RUS Bulletin 65-1
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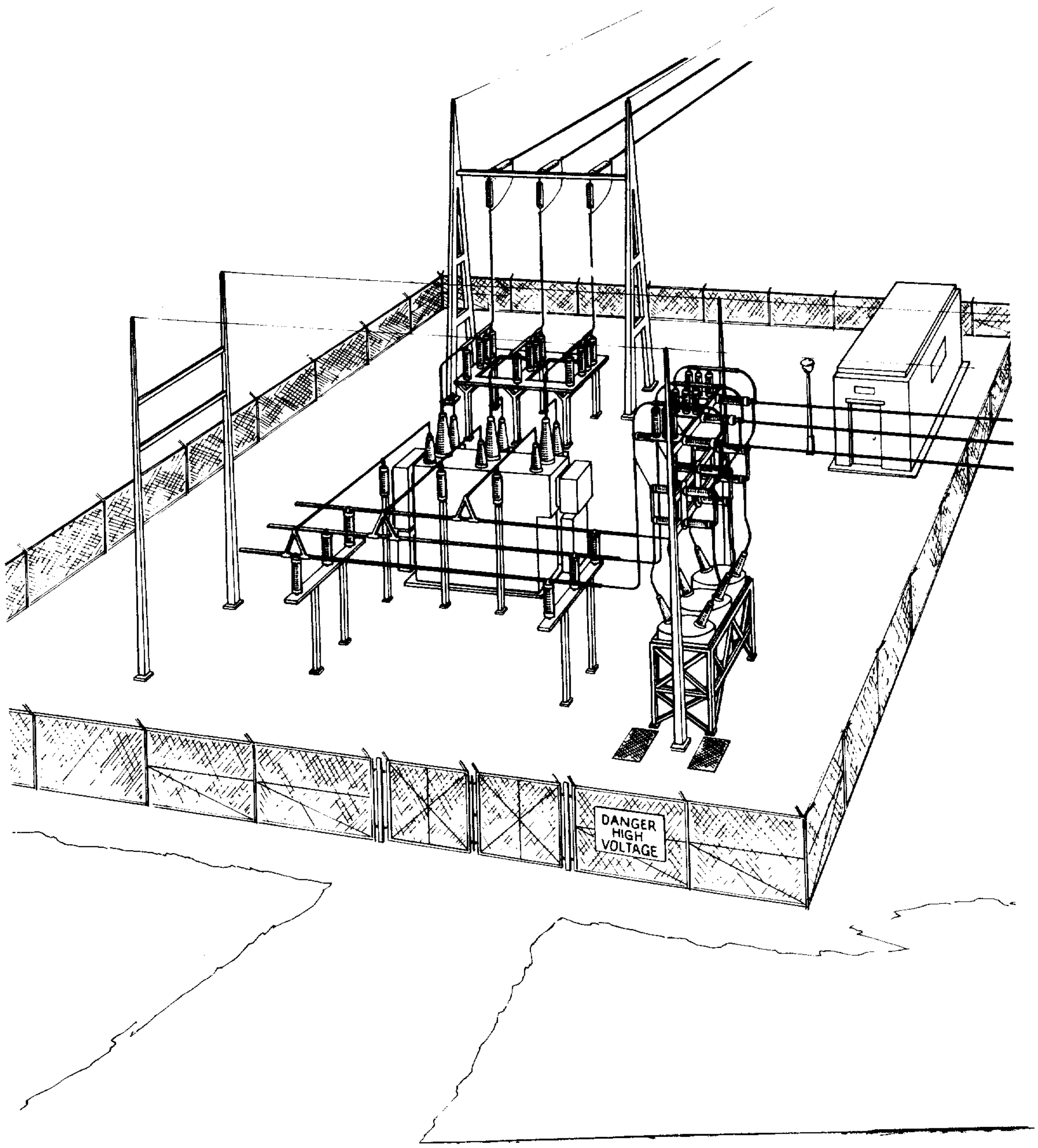
DESIGN GUIDE FOR
RURAL SUBSTATIONS



RURAL ELECTRIFICATION ADMINISTRATION • U.S. DEPARTMENT OF AGRICULTURE
REA BULLETIN 65-1
JUNE 1978

FOREWORD

This revision of REA Bulletin 65-1, "Design Guide for Rural Substations," provides engineering personnel with information covering all aspects of transmission and distribution substations through 230 kV. The only comprehensive publication of its kind in the industry specifically oriented toward rural substations, it is an excellent reference of fundamental engineering guidelines, minimum requirements and basic recommendations. The subject area includes structural, electrical, and mechanical aspects of substation construction as well as sections on layout, major equipment and maintenance.

Numerous cross references and examples, along with the latest in design technology, should be of great benefit to all engineers and engineering firms and particularly helpful to relatively inexperienced engineers beginning careers in substation design.

Assistant Administrator - Electric

Index:

REA BULLETIN 65-1

DESIGN GUIDE FOR RURAL SUBSTATIONS

POWER SUPPLY AND ENGINEERING STANDARDS DIVISION

RURAL ELECTRIFICATION ADMINISTRATION

U. S. DEPARTMENT OF AGRICULTURE

JUNE 1978

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TABLE OF CONTENTS

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CHAPTER I - INTRODUCTION

A. PREFACE

This bulletin is intended to provide design guidance for the increasing numbers of substations necessary to meet the growing electrical demands in areas served by REA Borrowers.

The substations should be designed, constructed, and operated to meet customers needs at the lowest possible cost commensurate with the quality of service desired. (See Bulletin 60-2, "Electric System Capacity.")

The typical system may include substations for voltage transformation, sectionalizing, distribution, and metering a number of times between generation and utilization.

B. PURPOSE AND SCOPE

This guide covers rural transmission and distribution air insulated, outdoor substations 230 kV (phase to phase) and below.

Most possible responsibilities of the Engineer are covered including preparation of construction drawings, material, equipment and labor specifications and any other engineering services that may be required.

The engineering function is generally more than furnishing of design and specifications. Recognition of this function becomes especially important when the REA Borrower employs an engineering firm to supplement its staff. See Bulletin 41-1, "Engineering Services for Electric Borrowers." The contract between the borrower and the engineering firm should be clear in its definition of the engineering functions to be performed. Within this bulletin, it must be understood that the term Engineer can mean either the Borrower's staff engineer(s) or the consultant's Engineer(s).

The Engineer must use these guidelines with his own experience and knowledge. A bibliography at the end of most chapters will aid in the search for more detailed information.

Use of this publication for substation design will usually result in an economical approach from a system standpoint. This should eventually result in the evolution of standard designs for a given system. Standardization is a desirable and achievable objective that should be pursued.

Technical advances and changes in codes and standards continue to proliferate in the electric power industry which could cause some of the material in this bulletin to become obsolete. Users must, therefore, continue their own efforts to keep up-to-date.

C. RELATIONSHIP OF SUBSTATION TO OVERALL POWER SYSTEM

A substation is part of a system and not an entity to itself. Normally, a power system is designed so that failure of a single component such as a transformer, transmission line, or distribution line will minimize the duration of the interruption and the number of customers affected by an interruption.

Failure of one component in a system often forces a greater than normal load to be carried by other components of the system. Such contingencies are normally planned for and incorporated into design criteria.

Most substations are designed so they will not require attendant personnel on a continuous basis. Remote indication, control, and metering and methods of communication are often provided so that systems and portions of systems can be monitored from a central point.

D. IMPORTANCE OF ADEQUATE SUBSTATION PLANNING AND ENGINEERING

(See Bulletin 60-2, "Electric System Capacity," and Bulletin 60-8, "System Planning Guide for Electric Distribution Systems.")

Substation planning considers the location, size, voltage, sources, loads and ultimate function of a substation. If the planning is not adhered to, the substation may require premature modification with the attendant unnecessary cost.

The Engineer's detail work must use valid requirements and criteria, appropriate guidelines, and his own expertise to provide construction drawings and associated documents. His ability in melding the diverse constraints into an acceptable design is essential.

During the design phase, the Engineer must not allow his intrinsic interest in solving technical problems to divert him from the use of nationally accepted standards, REA standards, or the concept of borrower's standard designs.

Adequate engineering design provides direction for construction, procurement of material, equipment, and future maintenance requirements while taking into account environmental, safety, and reliability considerations.

E. TYPES OF SUBSTATIONS

1. General

Substations may be categorized as distribution substations, transmission substations, switching substations, or any combination thereof.

Economies of scale influence substations to be as large as possible to minimize the number of them on the system. Conversely, practical system design and reliability considerations influence them to be as numerous as possible. It is a function of system studies to resolve these two viewpoints.

2. Distribution Substations

A distribution substation is a combination of switching, controlling and voltage stepdown equipment arranged to reduce subtransmission voltage to primary distribution voltage for distribution of electrical energy to residential, farm, commercial, and industrial loads.

Many rural distribution substation requirements range in capacity from one 1.5 MVA to three 5 MVA transformers and may be supplied radially, tapped from a subtransmission line, or may have two sources of supply. Most REA Borrower's substations have 12,470Y/7200 volt or 24,490Y/14,400 volt distribution circuits. Chapter IV covers the arrangements of such substations.

3. Transmission Substations

A transmission substation is a combination of switching, controlling and voltage stepdown equipment arranged to reduce transmission voltage to subtransmission voltage for distribution of electrical energy to distribution substations. Transmission substations frequently have two or more large transformers.

Transmission substations function as bulk power distribution centers, and their importance in the system often justifies bus and switching arrangements that are much more elaborate than distribution substations.

4. Switching Substations

A switching substation is a combination of switching and controlling equipment arranged to provide circuit protection and system switching flexibility.

Switching stations are becoming common on Borrower's systems. It is anticipated that REA financed systems will develop the need for various transmission switching arrangements. Flexible switching arrangements in a transmission network can often aid in maintaining reliable service under some abnormal or maintenance conditions.

CHAPTER II - GENERAL DESIGN CONSIDERATIONS

A. INITIAL AND ULTIMATE REQUIREMENTS

Borrowers should have both short and long range plans for the development of their systems. Timely development of the plans is essential for the physical and financial integrity of the systems, as well as to supply the customers with adequate service.

The long range plan identifies the requirements of a substation not only for its initial use but also for some years in the future. Consideration should be given to ultimate requirements in the initial design and economic comparisons made to discover what provisions are necessary for ease of addition.

The Engineer must appreciate that development plans embrace philosophies of operation and protection. Departures from the plans would likely jeopardize operation of the system.

The Engineer should use the Substation Design Summary covered in the Appendix of Chapter III to summarize basic design data.

B. SITE CONSIDERATIONS

One of the most critical factors in the design of a substation is its location and siting. Failure to give careful consideration to this problem can result in excessive investment in the number of substations and associated transmission and distribution facilities.

The following factors should be evaluated in relation to the selection of a substation site:

1. Location of present and future load center

2. Location of existing and future sources of power

3. Availability of suitable right-of-way and access to site by overhead or underground transmission and distribution circuits

4. Alternate land use considerations

5. Location of existing distribution lines

6. Nearness to all-weather highway and railroad siding; accessibility to heavy equipment under all weather conditions

7. Possible objections regarding appearance, noise or electrical effects

8. Possible objections regarding present and future impact on other private or public facilities

9. Soil resistivity

10. Drainage and soil conditions

11. Cost of earth removal, earth addition, and earthmoving

12. Atmospheric conditions - salt and industrial contamination

13. Space for future as well as present use

14. Land title limitations, zoning, and ordinance restrictions

15. General topographical features of site and immediately contiguous area. Avoidance of earthquake fault lines, flood plains, wetlands, and prime or unique farmlands where possible

16. Public safety

17. Security from theft, vandalism, damage, sabotage and vagaries of weather

18. Total cost including transmission and distribution lines with due consideration of environmental factors

19. Consideration of impact on rare and endangered species

C. ENVIRONMENTAL CONSIDERATIONS

1. General

REA Bulletin 20-21, "National Environmental Policy Act," calls for the implementation of the National Environmental Policy Act of 1969 as it relates to the REA program. Bulletin 20-21 also references additional authority, directives, and instructions relevant to protection of the environment.

As a general rule, stations 230 kV and above need Environmental Statements, while those below generally require a brief environmental report.

Attention is also called to the publication jointly issued by the Secretary of Agriculture and the Secretary of the Interior entitled "Environmental Criteria for Electric Transmission Systems." These criteria are recommended for designing, constructing, and operating transmission systems. Copies of "Environmental Criteria for Electric Transmission Systems" are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

2. Appearance

Appearance is becoming increasingly important to the public. In some areas, zoning regulations and suggestions by civic organizations often require screening, low profile designs, or other measures to improve appearance. The absence of such direct influence in rural areas should not be a reason for not considering newer design practices. The general trend is away from locating substations in a way that they are strikingly visible to the public. A substation set back from a heavily traveled road may require little or no architectural treatment to be acceptable.

The silhouette of a substation may be reduced in several ways including the use of solid-shape structural sections.

Engineering of transmission, distribution and substation facilities should be coordinated to develop the least overall objectional layout. Underground distribution circuit exits should be considered for special applications.

Lowering of substation profile may also be accomplished by means other than underground circuits although this approach may necessitate a larger ground area.

Landscaping or architectural screening may be appropriate to effectively blend a substation into the surrounding environment.

Generally, it is better to use complementary rather than contrasting colors. Sometimes, coloring can be used to blend the substation equipment into the background.

3. <u>Public Safety</u>

Substations should be safe for people who may have occasion to be near them.

The primary means of ensuring public safety at substations is by the erection of a suitable barrier such as a metal fence. Unless local restrictions are more conservative, the fence shall meet the minimum requirements specified in the National Electric Safety Code, Paragraph 1 (also may be identified as American National Standard C2.1 and National Bureau of Standards Handbook 110-1). Grounding of fences is further covered in Chapter IX; material and specification of fences is further covered in Chapter VI.

Additional means of protecting the public are through adequate design of all facilities inside the fence and the addition of a peripheral ground outside the fence. Protection against possible potential differences is discussed in Chapter IX.

Appropriate warning signs should be posted on the substation's peripheral barrier. The Engineer should specify their location and design. Substations no matter how small should have one sign per side minimum.

4. <u>Audible Noise</u>

Sources of audible noise within a substation include transformers, voltage regulators, circuit breakers and other intermittent noise generators.

Corona, which is localized incomplete dielectric failure, causes a hissing sound. The amount of this noise occurring at voltages of 230 kV and below is seldom serious. It is usually kept to a tolerable level if the same guidelines are followed as those for minimizing electrical effects; see Reference 5, "Electrostatic and Electromagnetic Effects."

Among the sources, transformers have the greatest potential for producing objectionable noise. The United States Environmental Protection Agency (EPA) has prepared a document "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With An Adequate Margin of Safety," (Report Number 550/9-74-004). The EPA has also published "Public Health and Welfare Criteria For Noise," (Report Number 550/9-73-002). There are several state and local noise ordinances known to exist, some of which contain regulations limiting noise at the property line. The reaction to noise can be subjective, so each substation situation should be analyzed.

To minimize the possibility of acoustical problems, the Engineer should consider the following:

a. Site Selection - If the substation must be located in or near a residential area, select a site the greatest distance from nearby residences, and, if possible, avoid a direct line of sight with them. A site with natural barriers such as mounds or shrubbery is desirable, since this can help reduce the psychological impact of a new installation.

b. Layout Design - Good practice for noise control is to locate a transformer the maximum distance from a fence. Once the transformer is located, its noise level at any distance can be determined by using a standard formula; See "Standard Handbook for Electrical Engineers" published by McGraw-Hill. If noise is anticipated to be a problem, the equipment layout should be arranged to permit the installation of a sound barrier. Anticipated future requirements should also be considered, since additional transformers will increase the noise level.

c. Level - As a general rule, substation noise will not be a problem if, when combined with the ambient noise, it is less than 5 dBA above the ambient noise level. It may be desirable to measure the ambient noise levels at locations of concern. Measurements should be taken during the quietest periods, approximately midnight to 4 a.m. Calculation of resultant sound level will then indicate whether further study is required. The references in this chapter's bibliography suggest methods to rigorously address noise problems.

d. Transformers - Chapter V, "Major Equipment," Section A "Power Transformers" provides additional guidelines.

5. Electrostatic and Electromagnetic Effects

Consideration should be given to preventing radio and television interference that could result if there is visible corona. Significant corona could be caused by energized parts having small radii or from small diameter conductors, particularly when conducive climatic conditions prevail. Experience has shown, though, that conductor fittings and energized parts other than conductors do not produce serious corona at phase to phase voltages of 230 kV and below.

It is necessary, however, to give some consideration to the size of conductors. Chapter IV gives guidelines for fault and load carrying conductors. Connections to equipment such as voltage transformers and coupling capacitors should not be sized from a current carrying standpoint only. They should, from a corona standpoint, be not smaller than 3/0 at 230 kV or 1/0 at 161 and 138 kV.

6. Effluent

The Environmental Protection Agency has promulgated regulations to eliminate the pollution of navigable waterways. The essence of these regulations is that in the event of the failure of containment of a pollutant, such as transformer or circuit breaker oil, no significant quantity of such pollutant may be allowed to enter a navigable waterway. No absolute prevention is required if such pollution is not reasonably expected. However, it is necessary to have a plan of action for disposing of effluent should spills or leaks occur. Some oil pollution prevention measures are described in Chapter VIII.

Until very recently, askarel was used in almost all capacitors. This type of impregnant is being phased out, due to its resistance to biodegradation, in favor of materials potentially less harmful to the environment. ANSI Standard C107.1, "Guidelines for Handling and Disposal of Capacitor and Transformer-Grade Askarels Containing Polychlorinated Biphenyls" gives a comprehensive review of the subject.

D. NATURE CONSIDERATIONS

1. Weather

a. General - As dependence on the use of electricity grows, it is increasingly important that substations operate more reliably in extremes of weather than in the past.

b. Temperature - It is necessary to design a substation for the extreme temperatures expected.

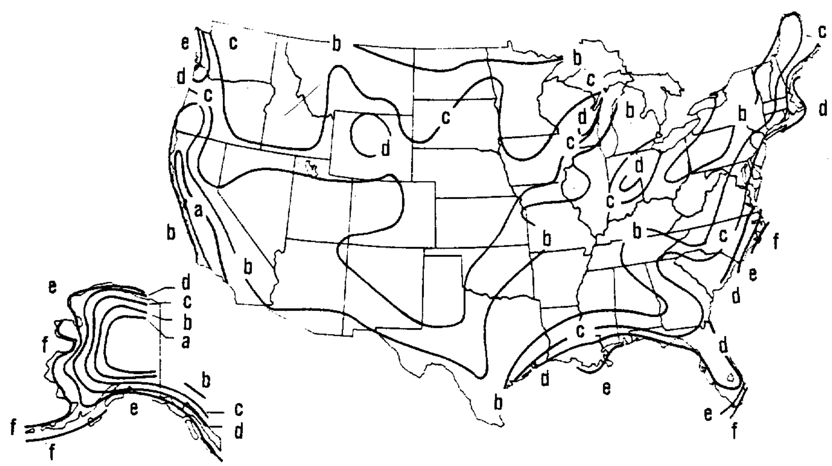
c. Wind - As a minimum, substations should be resistant to wind velocities as shown in Figure II-1. (This is a modified reproduction of Figure 1 and part of Table 4 of ANSI Std. A58.1 "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures.") Chapter IV, "Physical Layout," and Chapter VII, "Structures," give specific guidelines on design. Local conditions may dictate more stringent wind designs.

d. Ice - A substation must continue to operate despite ice accumulation. Generally, the consensus equipment standards specify ice loadings to be withstood for both electrical and mechanical factors. The complete substation assembly must also be undamaged by ice accumulation. From ice accumulation history for a given substation's location, the Engineer can judge whether or not more severe loadings than consensus equipment standards are necessary. Additional viewpoints on ice loading are given in Chapter IV, "Physical Layout," and Chapter VII, "Structures."

e. Rain - A substation should be designed to be operable under predictable conditions of rainfall. Additionally, it is desirable that a substation be so drainable as to exhibit little standing water within a few hours after a heavy rainfall. See Chapter VI, "Site Design," for guidelines.

f. Snow - Snow introduces an extremely variable hazard to substations because of uncertainties in drifting and accumulation. The substation must be impervious to snow damage, and consideration must be given to snow accumulation and the maintenance of clearances. The Engineer should seek local data on this weather variable.

g. Electrical Storms - The two measures normally employed for lightning protection are surge arresters and shielding. Application guidelines for surge arresters are given in Chapters IV and V. Surge arresters provide very little protection against direct strokes. Shielding is provided by overhead wires, masts which are extensions of structures, or independent masts as covered in Chapter IV. A combination of surge arresters and shielding will reduce the probability of damage from lightning.



	KM/HR	MPH
(a)	96.5	(60)
(b)	112.6	(70)
(c)	128.7	(80)
(d)	144.8	(90)
(e)	161.0	(100)
(f)	177.0	(110)

HAWAII 128.7 (80)

FIGURE II-1

Basic Wind Speed in Kilometers per Hour (Miles per Hour)
Annual Extreme Fastest-Mile Speed 9.144 Meters (30 Feet)
Above Ground, 50-Year Mean Recurrence Interval

h. Humidity - Consideration should be given to installation of differential thermostat controlled heating in outdoor cabinets such as circuit breaker control cabinets where condensation could be a problem. In areas where fog occurs often and particularly where airborne contamination exists, frequent insulator flashovers may occur. Methods of reducing flashovers include the application of special insulation and insulator cleaning.

2. Altitude

Equipment that depends on air for its insulating and cooling medium will have a higher temperature rise and a lower dielectric strength when operated at higher altitudes; see ANSI Standard C37.3, "Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports."

Surge arresters are designed for satisfactory operation at elevations up to a limit specified by the manufacturer. Applications above this limit are considered special and the manufacturer should be consulted for his recommendation.

Dielectric strength of air and current ratings of conductors operated in air should be multiplied by factors shown in Columns "A" and "B" of Table II-1.

3. Earthquakes

No substation subjected to intense earthquakes could be expected to escape undamaged. Therefore, earthquake damage must be considered in certain areas.

TABLE II-1
ALTITUDE CORRECTION FACTORS
FOR SUBSTATION EQUIPMENT

Altitude		Altitude Correction Factor to be Applied to:		
		A	B	C
Meters	Feet	Dielectric Strength	Current Rating	Ambient Temperatures
1000	3300	1.00	1.00	1.00
1200	4000	0.98	0.995	0.992
1500	5000	0.95	0.99	0.980
1800	6000	0.92	0.985	0.968
2100	7000	0.89	0.98	0.956
2400	8000	0.86	0.97	0.944
2700	9000	0.83	0.965	0.932
3000	10000	0.80	0.96	0.920
3600	12000	0.75	0.95	0.896
4200	14000	0.70	0.935	0.872

Much substation equipment is inherently shock resistant. The assembly of the total substation - foundations, structures, equipment, insulation and conductors - may not be. Designs to minimize damage probability should be followed in Seismic Risk Zones 2 and 3, Reference Figures II-2, II-3 and II-4. Application of the guidelines given in succeeding Chapters will minimize the probability of damage to substations from seismic forces.

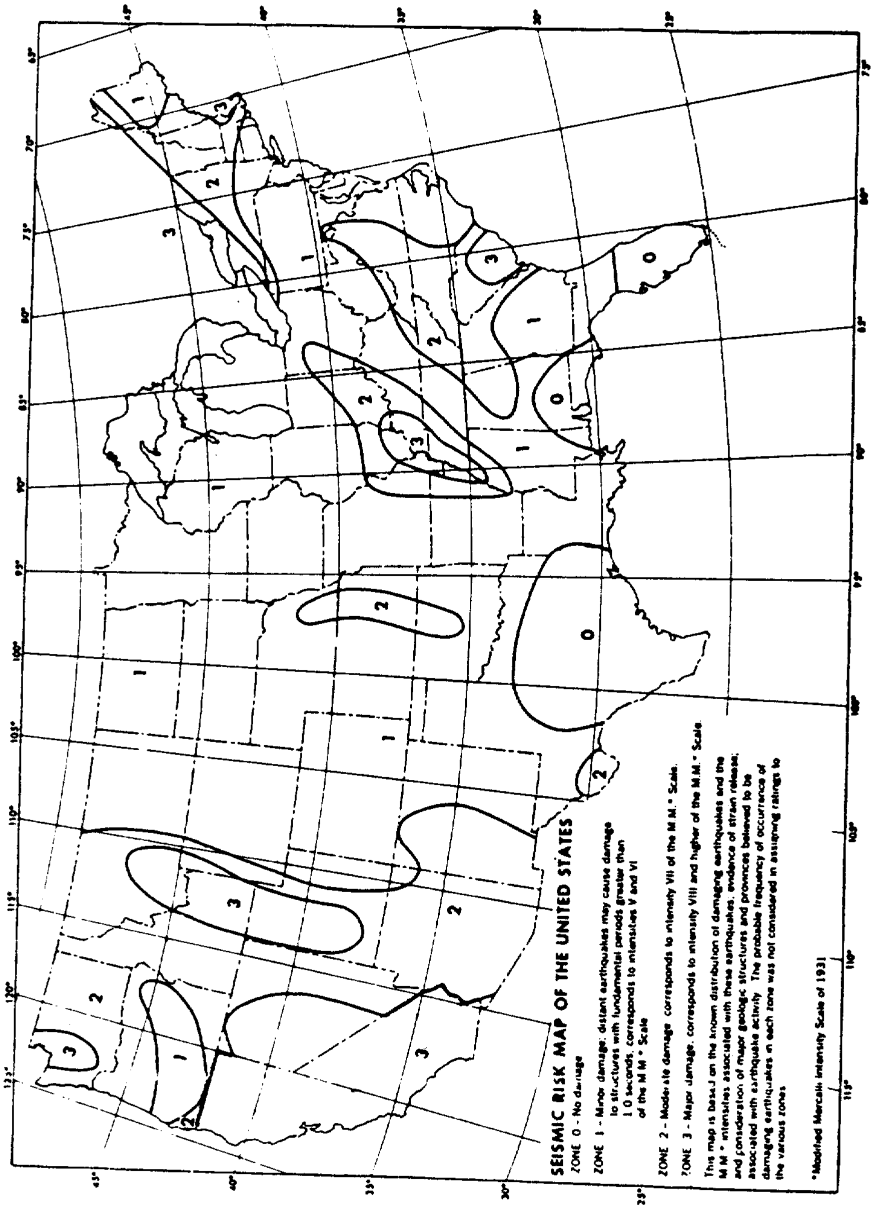


FIGURE II-2 SEISMIC ZONE MAP OF THE UNITED STATES

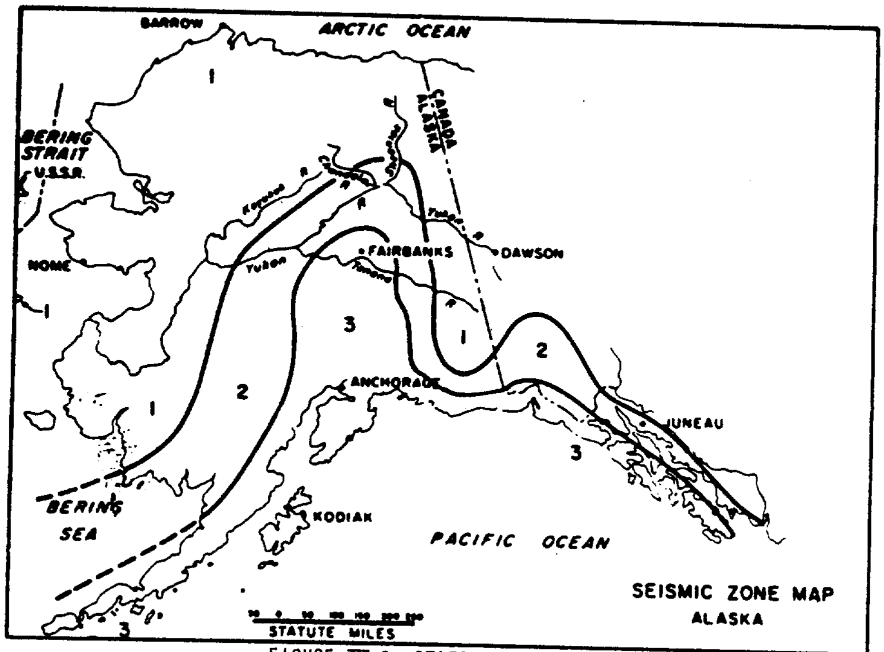


FIGURE II-3 STATE OF ALASKA

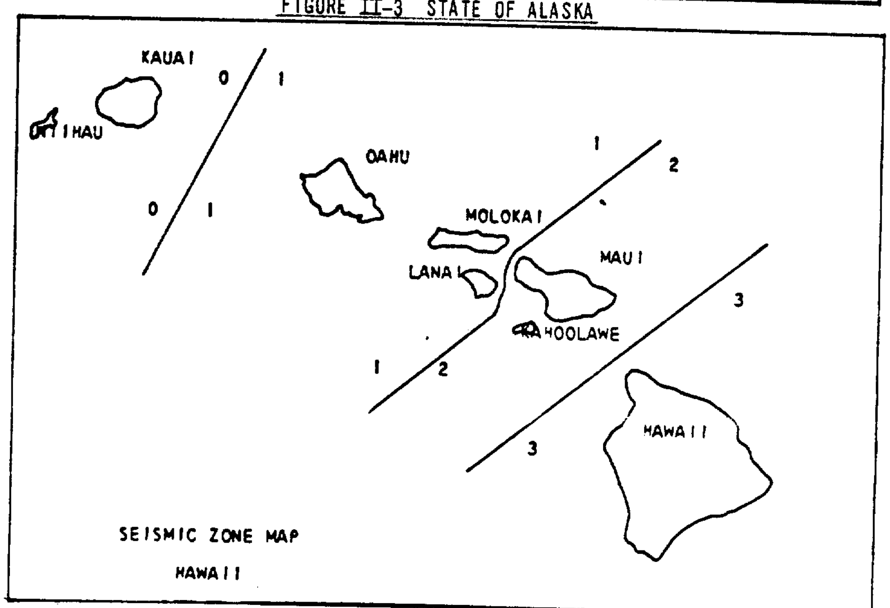


FIGURE II-4 STATE OF HAWAII

4. Wildlife & Livestock

A substation should be protected from wildlife and livestock. The primary means is the perimeter barrier. This is generally a chain link fence that keeps out larger animals. It may also be necessary to have rodent and/or reptile barriers. It is recommended that all substation materials be nonnutrients, since impregnable barriers would be too costly. Insect screening should be applied where local experience indicates. Bird damage is usually minimized by avoiding attractive nesting and perching sites. Keeping clearances adequate for local bird species should be kept in mind because possible perching spots usually cannot be eliminated.

5. Air-Borne Foreign Material

Air-borne seeds, leaves, debris, dust and salts that are local phenomena could be a problem. Build-up could occur that would compromise electrical insulation or would interfere with cooling. Recognition to such conditions should be given in the design of a substation.

E. INTERFACING

A substation will interface with a vehicle roadway, area drainage, communication system and electric power lines. Sufficient lead time must be allowed to coordinate activities with both public agencies for roadway access and with communications agencies for communications facilities. Chapter XVI provides details on communications considerations.

There should be no difficulty in ensuring proper interfacing with distribution, subtransmission, and transmission lines. Timely plans should be made so there is mutual agreement between the substation engineer and the lines engineer on the following:

1. Connecting hardware procurement responsibility
2. Mating of hardware to line support structure
3. Line identifications and electrical connections to suit planning engineering requirements
4. Substation orientation and line approach
5. Phase conductor and shield wire identification

6. Pull-off elevations, spacings, tensions and angles. Confusion sometimes occurs in the matter of specifying tensions. In some cases, line tensions on the line side of a line approach or dead end structure will be much greater than on the line support structure in the substation. The tension specified to the substation engineer should be the tension that will be a maximum on the substation line support structure for the wire under the most severe combination of temperature, wind and ice loading. The condition at which maximum tension occurs must be known in order to select overload factors. Chapter VII, "Structures," covers overload factor selection.

As a general rule, takeoff tensions should not exceed 8900 newtons (2000 pounds) per conductor for small distribution substations.

F. RELIABILITY

A prime objective in the operation of an electric power system is to provide reliable service within acceptable voltage limits. Bulletin 60-7, "Service Reliability," provides information on reliability. Borrowers following criteria in this guide should have reasonably reliable substations.

G. OPERATING CONSIDERATIONS

For simplicity and ease of maintenance, substation equipment arrangements, electrical connections, signs and nameplates should be as straightforward as possible. Novel situations are to be avoided lest they contribute to the possibility of operating errors.

A substation may occasionally experience emergency operating conditions. Depending on the length of time, the provision of unusual current carrying capacity of some equipment or connections may have to be considered in the design.

H. SAFETY CONSIDERATIONS

It is paramount that substations be safe for the Borrower's operating and maintenance personnel. Practical approaches include the employment and training of qualified personnel, appropriate working rules and procedures, proper design and correct construction. Safeguarding of equipment must also be a consideration in substation design.

Minimum personnel working standards are prescribed by regulations issued by the Occupational Safety and Health Administration (OSHA). The basic documents have been published in Title 29, Code of Federal Regulations Part 1910 for General Industry and Part 1926 for Construction. In addition, various states may have standards the same as or stricter than those of OSHA. The Engineer is expected to follow the regulations appropriate to the jurisdiction in which a substation is built.

It should be recognized that this Bulletin presents minimum guidelines. The Engineer has the responsibility for compliance with the applicable requirements of REA, the National Electric Safety Code, National Electric Code, OSHA and local regulations.

I. MAINTENANCE CONSIDERATIONS

Thought must be given in design to allow maintenance with a minimum impact on a substation's function. Allocation of adequate working space will make maintenance more convenient.

Selection of durable equipment will minimize the need for maintenance. Since it is to the vendor's advantage to offer equipment with minimal maintenance requirements, it is desirable that the Engineer keep aware of such improvements in available products.

CHAPTER II - GENERAL DESIGN CONSIDERATIONS

REFERENCES

1. U.S. Environmental Protection Agency, Information On Levels Of Environmental Noise Requisite To Protect Public Health And Welfare With An Adequate Margin Of Safety, Report Number 550/9-74-004, Washington, D.C., March, 1974.

2. C. R. Bragdon, "Municipal Noise Ordinances: 1975", Sound and Vibration, December, 1975, Volume 9, Number 12, pp. 24-30.

3. U.S. Environmental Protection Agency, Public Health And Welfare Criteria For Noise, Report Number 550/9-73-002, Washington, D.C., July 27, 1973.

4. Fink and Carroll, Standard Handbook For Electrical Engineers, 10th Edition, 1968, McGraw-Hill, Section 11-100.

5. R. S. Pedersen, Audible Noise Reduction In New And Existing Substations, Engineering and Operating Conference, Pacific Coast Electrical Association, San Francisco, California, March 18-19, 1976.

6. M. W. Schulz, Transformer Audible Noise, IEEE Power Engineering Society Summer Meeting, Portland, Oregon, July 17-23, 1976.

7. E. B. Lawless, III, Noise Control Regulations And Effects Upon Substation Design, Annual Conference of Engineering and Operation Division, Southeastern Electric Exchange, New Orleans, Louisiana, April 26-27, 1976.

CHAPTER III - DOCUMENTS

A. GENERAL

The primary function of a substation design Engineer is to produce or supervise the development of formal plans from which a substation can be constructed.

Following is a list of documents or studies that may also be required as part of the Engineer's responsibility. The timing and chronological order of the documents may vary, depending upon the particular substation's requirements.

1. Site Comparison and Suitability Evaluation
2. Environmental Impact Statement (input) or Brief Environmental Report
3. Substation Design Summary Form
4. Functional One Line Diagram
5. Application for zoning variance or change
6. Specifications for Equipment
7. Request for Proposals to Furnish Equipment
8. Evaluation of Proposals to Furnish Equipment
9. Construction Plan Drawings
10. Backup Sketches and Calculations for Construction Plans
11. Substation Drawings not Actually Used for Construction (Detailed one line, elementary, and schematic diagrams)
12. Requisitions for Material and Equipment
13. Application for Building Permit
14. Application for Permits for Roadway and Drainage Interface

15. Application for FCC License

16. Construction Specifications

17. Inquiry for Proposals to Furnish Construction

18. Evaluation of Contractor's Proposals

19. Comment Letters on Equipment Vendors' Submittals

20. Calculations for Selection of Protective Relaying and Devices

21. Economic Comparisons

During the formulation of design, some sketching and calculations are required in order to arrive at optimum designs. While these are not a part of the formal plans, they are nevertheless useful in planning and are often valuable for future reference.

All documentation shall be done in metric units with English units as a parenthetical reference. For example, a dimension on a drawing might be 1.98 m. (6'-6").

B. NEED FOR DOCUMENTATION

Documentation establishes a basis by which the Engineer expresses and evaluates his own ideas. A document serves as a vehicle for the Borrower and Engineer to reach agreement on a subject. In its final form, a document fulfills its primary role of establishing design and functional requirements. A document also serves as a record of what was built, specified, or evaluated. The importance of good records in substation design deserves emphasis. Successful designs and accurate records are convenient references for designs and for standardized approaches for new substations. Records can also be very useful in diagnosing and correcting problems.

C. PROCEDURES

REA has procedures that must be followed and, in addition, each Borrower may have certain procedures that suit his needs.

The chronology of a substation is generally as shown below -- elapsed times varying according to a particular project's requirements. It is desirable to bear in mind consultation with the REA field representative. See Bulletin 40-6, "Construction Methods and Purchase of Materials and Equipment," and

Bulletin 81-9, "Preparation of Plans and Specifications for Distribution and Transmission Facilities."

Substation Design Chronology

1. Identification of substation need from power supply study or Borrower's long range plan

2. Pre-loan engineering

3. Application for Loan; See Bulletin 20-2, "Loan Processing for Distribution Borrowers"

4. Loan approval

5. Final procurement of real estate

6. Selection of major equipment

7. Preparation of plans and specifications; See Bulletin 81-9, "Preparation of Plans and Specifications for Distribution and Transmission Facilities"

8. REA Form 764, "Substation and Switching Station Erection Contract." This will generally be required for systems with limited construction forces.

9. Approval of plans and specifications by Borrower's board of directors; see Bulletin 40-6, "Construction Methods and Purchase of Materials and Equipment"

10. Design approval by REA as required

11. Selection of a construction contractor
    When competitive bids are to be taken for substation construction, the Engineer's role is that described in Bulletin 40-6. Also, see REA Form 764, "Substation and Switching Station Erection Contract"

12. Construction

13. Inspection; see REA Form 235, "Engineering Service Contract Electric Substation Design and Construction," and Bulletin 81-6, "Close-Out Procedures and Documents for Contract Construction of Distribution and Transmission Facilities"

14. Testing

15. Energizing

D. PROCUREMENT

The methods and documentation for obtaining substation equipment are as follows:

1. Purchase order following informal quotations, or

2. Contract and purchase order following formal competitive bidding

Guidelines and procedures applicable to the selection of materials and equipment include the following REA Bulletins:

Bulletin 40-1, "Specifications and Standards for Materials and Equipment"

Bulletin 40-6, "Construction Methods and Purchase of Materials and Equipment"

Bulletin 43-5, "List of Materials Acceptable for Use on Systems of REA Electrification Borrowers"

Bulletin 43-6, "Selection and Inspection of Materials and Equipment"

Bulletin 43-9, "'Buy American' Requirement"

Bulletin 44-7, "Acceptance of Standards, Standards Specifications, Drawings, Materials and Equipment for the Electric and Telephone Programs"

The size and complexity of a project can greatly influence the choices in procurement. Lead times for procurement of major and/or special equipment in many cases may favor incremental purchases of equipment.

Smaller projects may lend themselves more to "standard package" type procurement while the procurement for larger projects may require many vendors.

E. DRAWINGS

1. General

The smaller and less complex substations naturally do not need as many different types of drawings as the larger more complicated substations.

For a basic distribution substation, the "One Line Diagram" and "Plot Plan" may be the drawings that need to be custom made by the Engineer. For example, if a substation is small, it may be possible to show foundation details on the "Plot Plan" drawing. In a similar manner, the grounding layout and details might be shown on a "Plot Plan."

Larger substations will, of necessity, require more extensive documentation. REA Form 235, "Engineering Services Contract - Electric Substation Design and Construction," gives a basic list of drawings often necessary.

2. Quality

a. REA Bulletin 60-1

Substation drawings of any kind should conform to the requirements of Bulletin 60-1, "Circuit Diagrams, Electrical Data Sheets and Other Drawings for Systems of Electric Borrowers." The drawing material, "tracing linen or paper," as applicable, is interpreted as a durable, commercially available material satisfactory for making reproducible pencil drawings.

b. Drafting Practice

It is recommended that drafting practices be in accordance with "American Drafting Standards Manual," ANSI Y14. Prints of the drawings will be used in construction, not always under the most convenient conditions. Equipment outlines are preferred to detailed pictorial repre-sentations. Pertinent component interfaces and connec-tions should be illustrated in adequate detail for construction and record purposes. Pertinent distances must be dimensioned. Drawings, though made to scale, should not have to be scaled for construction purposes. Thought should be given to choosing scales and lettering sizes appropriate for the type of drawing. It would be desirable to use bar type graphic scales on all drawings, since many of them may be reproduced to different sizes. Plans, elevations, and sections should be organized for maximum clarity. Tolerances should be noted on drawings such as those that specify foundation anchor bolt locations and equipment mounting holes on control panels. Simplicity and clarity of drawings are essential.

c. Legends, Notes, Symbols

A definitive legend should be on the first sheet of each type of drawing. This legend should not only include the standard symbols, but all special symbols or designations. A set of notes is often found to be a desirable supplement on a drawing. The guideline here is that judgment must be exercised to avoid overdoing notation. It may be better to consider additional details on the drawings rather than a long list of notes. Electrical symbols should be in accordance with "Graphic Symbols for Electrical and Electronics Diagrams," ANSI Y14.15.

d. Reference Drawings

Proper care must be given to the listing of reference drawings to ensure a coherent, concise pattern.

e. Titles

Drawing titles should be concise, accurate, and specific. They should not be so general that the drawing itself must be viewed to see what it covers.

f. Approvals

Every drawing or revision to a drawing should indicate the proper approvals and dates.

3. Types of Drawings

Following are the main types of substation construction and reference drawings often required. The appendix to this chapter has check lists covering some types of drawings. It is recommended that the Engineer use checklists as a design quality control tool.

a. One Line Diagram - Switching

b. One Line Diagram - Functional Relaying

The one line diagrams are the major substation reference drawings and require special emphasis. These should be the first drawings prepared. The switching and functional relaying information may appear on the same one line diagram if the presentation is not too complicated. It is recommended that One Line Diagrams be prepared as follows:

(1) Use acceptable symbols. Identify all symbols in the legend.

(2) Arrange equipment symbols geographically correct, as much as practical, with respect to each other.

(3) Put a north arrow on the drawing to orient the diagram the same as the Electrical Plot Plan.

(4) Apply an appropriate numbering scheme for major equipment.

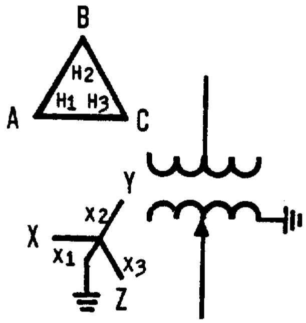
(5) Identify buses and line connections.

(6) Lines representing power carrying conductors should be heavier than those representing connections to voltage transformers, to current transformer secondary windings, etc.

(7) Vector relations and phasing should be specified, where appropriate.

(8) Acceptable symbols for some of the most common substation equipment are illustrated below in Figures III-1 through III-18. Generally, these symbols are based upon ANSI Y14.15. Drafting templates are commercially available to assist in developing the one line diagrams. Each symbol should be accompanied by the pertinent equipment information indicated.

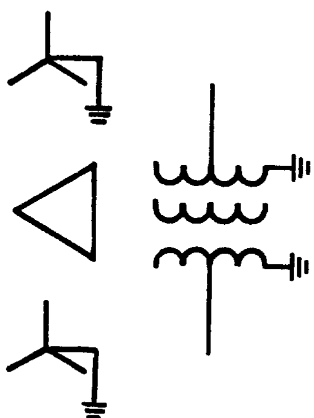
Figures III-19, III-20, and III-21 give elementary examples of symbols in combination. Figure III-19 shows a conceptual One Line Diagram of a transmission substation. This is merely to illustrate use of some



MANUFACTURER	
TYPE	OA/FA/FOA ETC. AS APPLICABLE
CAPACITY	(_/_/_ MVA)
VOLTAGE	(_/_/_/ETC _/_-_KV)
IMPEDANCE	(_ OHMS HV-LV)
	(SHOW PHASING AND TERMINAL DESIGNATION ON VECTORS)

FIGURE III-1 POWER TRANSFORMER

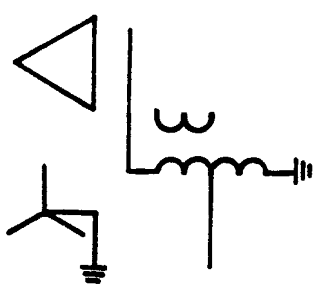
(SHOWN WITH LOAD TAP CHANGER ON LOW VOLTAGE SIDE)



INFORMATION SAME AS FIGURE 1 ABOVE EXCEPT INCLUDE ALL IMPEDANCES

(HV-LV __ % ON __ MVA BASE)
(HV-TV __ % ON __ MVA BASE)
(LV-TV __ % ON __ MVA BASE)

FIGURE III-2 THREE PHASE TRANSFORMER WITH TERTIARY



INFORMATION SIMILAR TO FIGURE 1 ABOVE

FIGURE III-3 THREE PHASE AUTO-TRANSFORMER

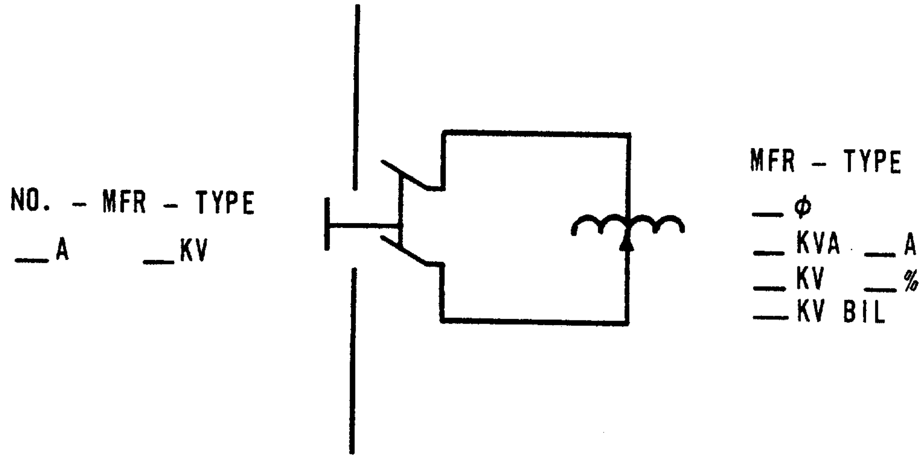


FIGURE III-4 STEP VOLTAGE REGULATOR WITH BYPASS SWITCH

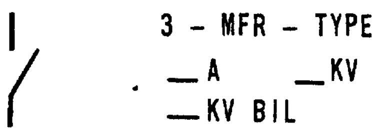


FIGURE III-5 HOOK STICK OPERATED DISCONNECTING SWITCH

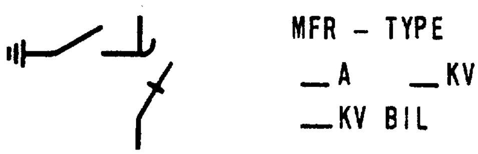
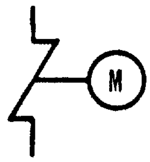


FIGURE III-6 THREE PHASE GANG OPERATED DISCONNECTING SWITCH WITH HORN GAPS AND GROUNDING SWITCH



MFR - TYPE

__ A __ KV

__ KV BIL

FIGURE III-7 THREE PHASE DOUBLE SIDE BREAK DISCONNECTING SWITCH WITH MOTOR OPERATOR

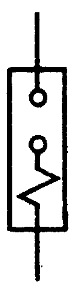
1 OR 3 - MFR - TYPE

__ A __ KV

__ A LINK (OR MFR CAT. NO.)

__ KV BIL

FIGURE III-8 FUSED DISCONNECT



1 OR 3 - MFR - TYPE - 1 OR 3Φ

__ A __ KV

__ KV BIL

FIGURE III-9 OIL CIRCUIT RECLOSER

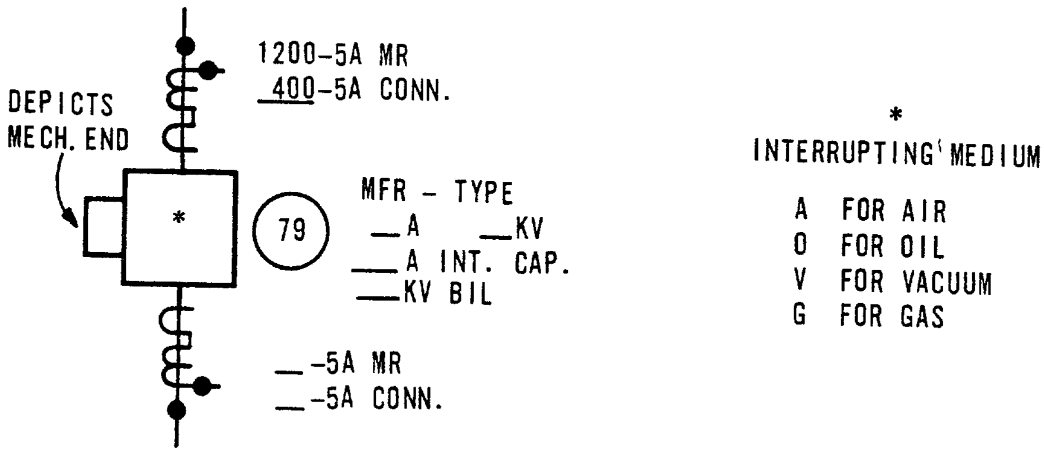


FIGURE III-10 CIRCUIT BREAKER

(SHOWN WITH BUSHING TYPE CT'S AND RECLOSING RELAY)
(SHOW POLARITY MARKS IF ONE LINE FUNCTIONAL RELAYING DIAGRAM)

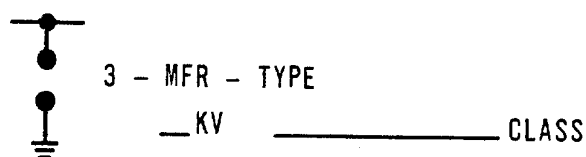


FIGURE III-11 SURGE ARRESTER

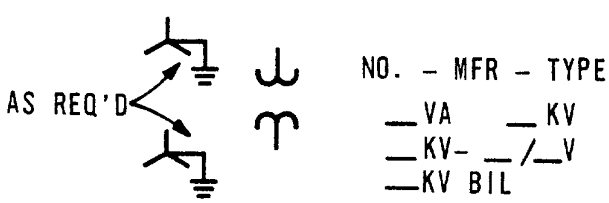


FIGURE III-12 VOLTAGE TRANSFORMER

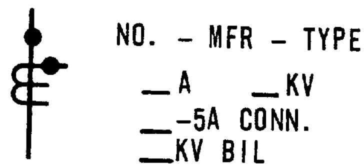


FIGURE III-13 CURRENT TRANSFORMER

(SHOW POLARITY MARKS ON FUNCTIONAL RELAYING ONE LINE DIAGRAM)

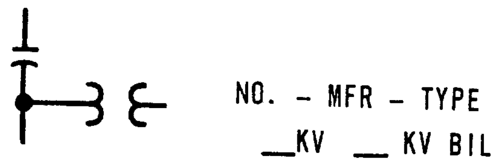


FIGURE III-14 COUPLING CAPACITOR WITH VOLTAGE TRANSFORMER

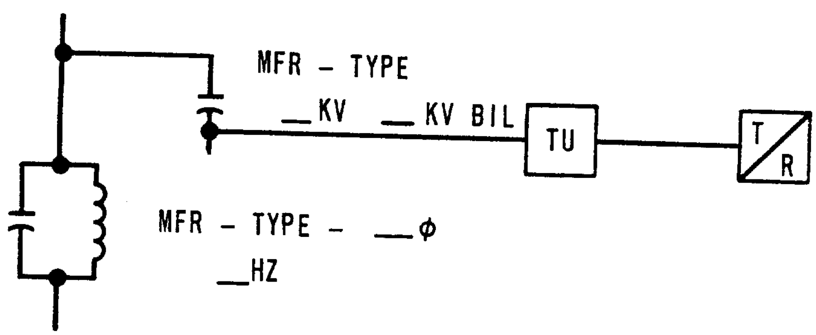


FIGURE III-15 COUPLING CAPACITOR, WAVE TRAP TUNING UNIT AND POWER LINE CARRIER TRANSMITTER/RECEIVER

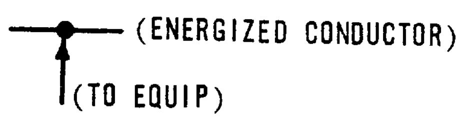


FIGURE III-16
DISCONNECTING CLAMP

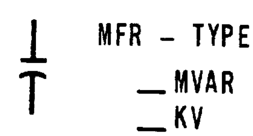
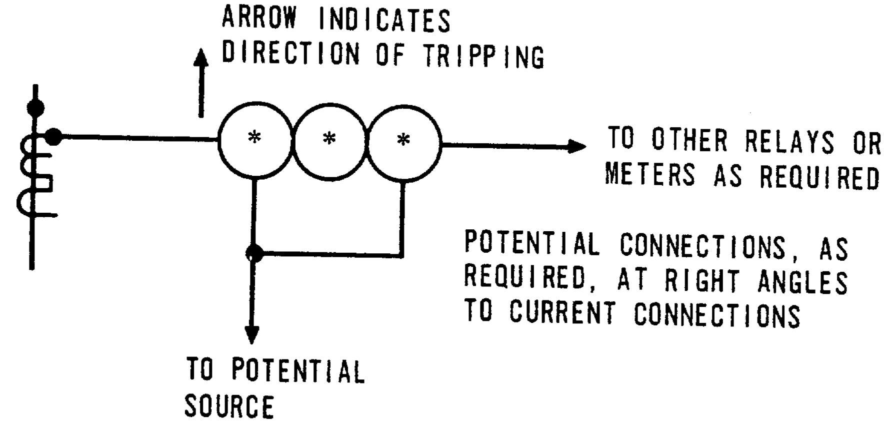


FIGURE III-17
SHUNT CAPACITOR



* A PARTIAL LISTING OF DEVICES AS FOLLOWS:

A (FOR AMMETER)
V (FOR VOLTMETER)
W (FOR WATTMETER)
WH (FOR WATT-HOUR METER)
VAR (FOR VOLT AMPERE REACTIVE METER)

OR A NUMBER IN ACCORDANCE WITH ANSI STD. C37.5 SUCH AS THE FOLLOWING COMMONLY USED NUMBERS:

21 (DISTANCE RELAY)
27 (UNDERVOLTAGE RELAY)
32 (DIRECTIONAL POWER RELAY)
50 (INSTANTANEOUS OVERCURRENT RELAY)
51 (AC TIME OVERCURRENT RELAY)
67 (AC DIRECTIONAL OVERCURRENT RELAY)
74 (ALARM RELAY)
87 (DIFFERENTIAL PROTECTIVE RELAY)

FIGURE III-18 TYPICAL RELAY AND METER REPRESENTATION

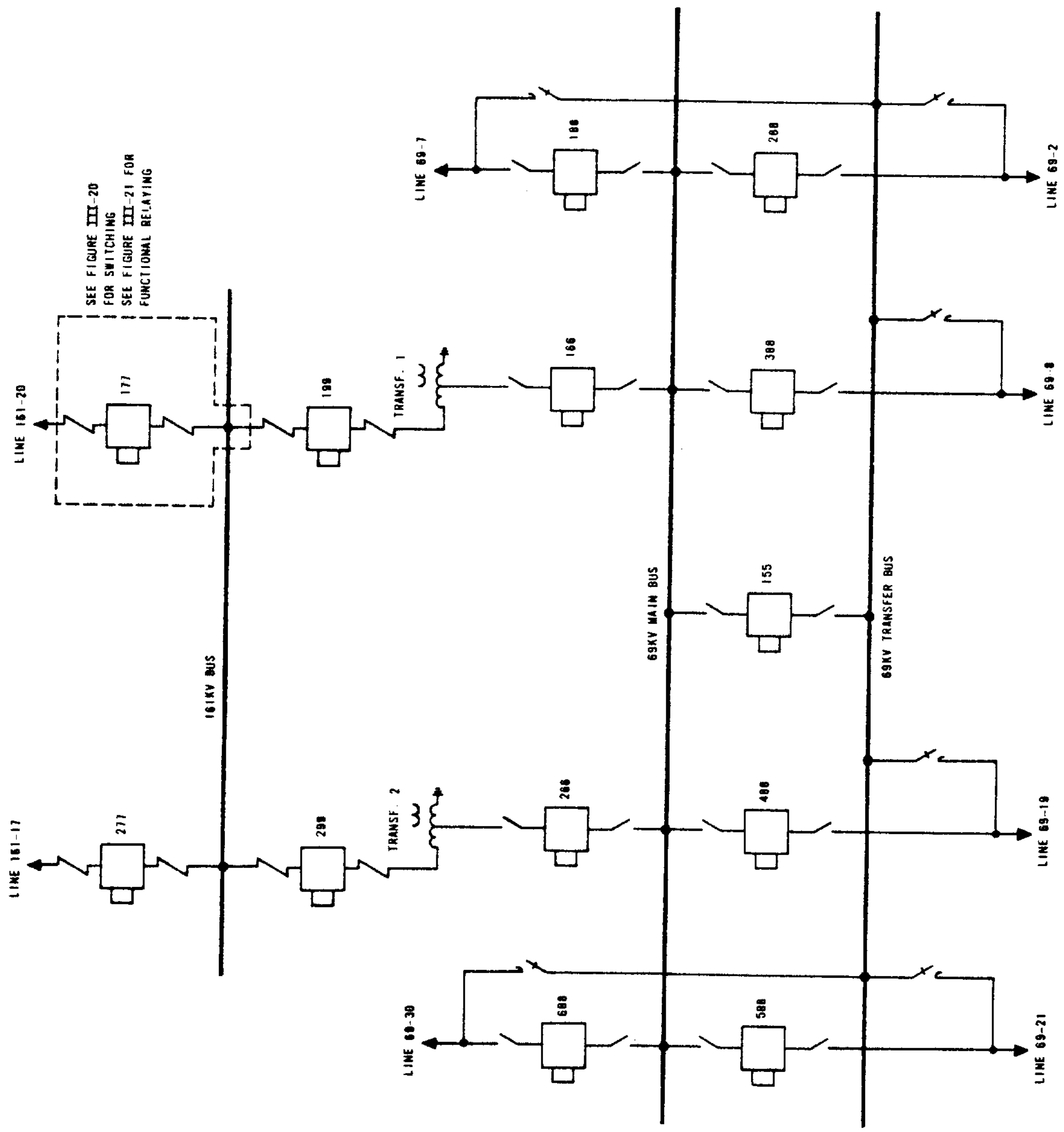


FIGURE III-19 CONCEPTUAL ONE LINE DIAGRAM

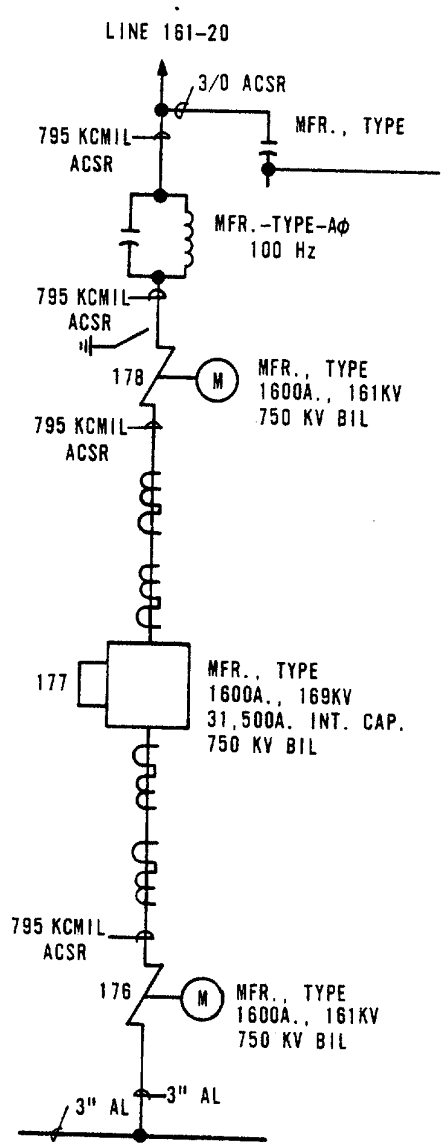


FIGURE III-20 PARTIAL SWITCHING ONE LINE DIAGRAM (SEE FIGURE III-19)

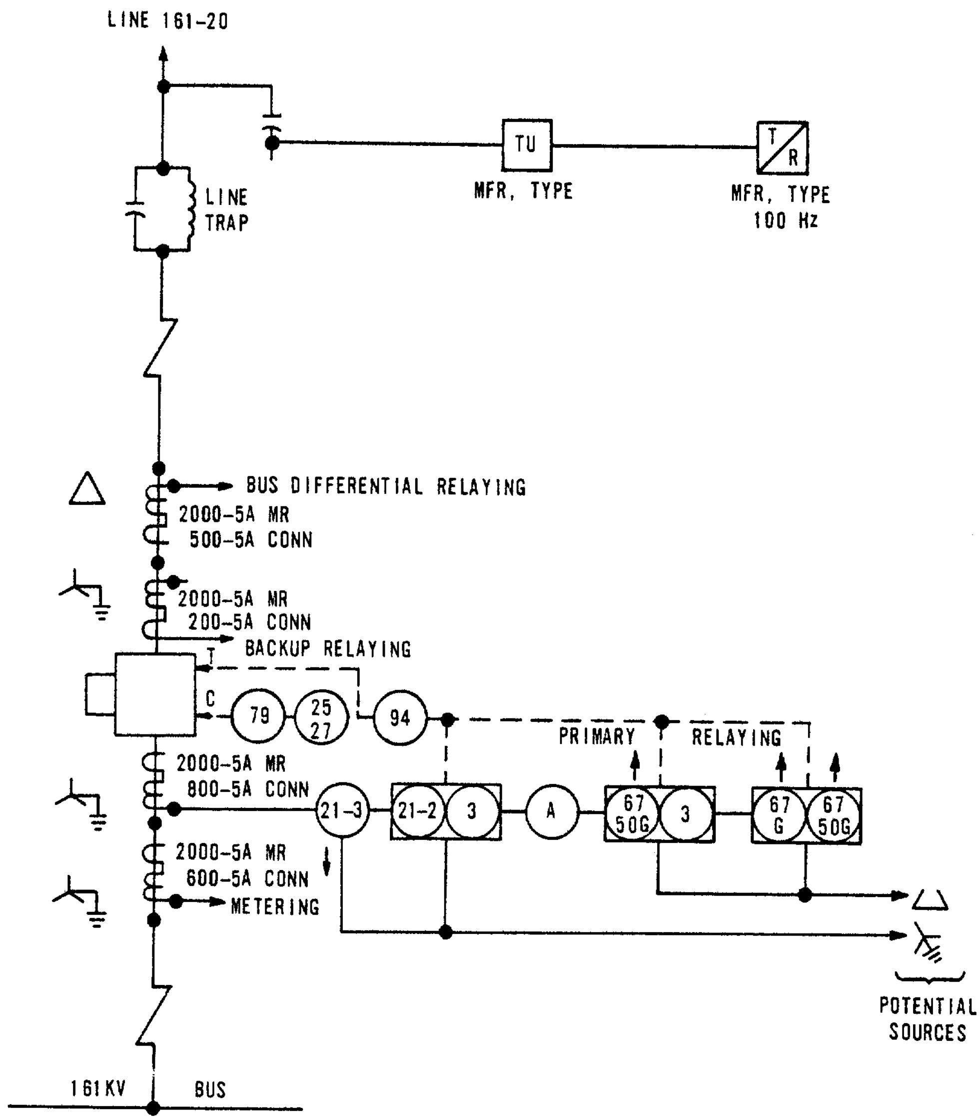


FIGURE III-21 PARTIAL FUNCTIONAL RELAYING
ONE LINE DIAGRAM (SEE FIGURE III-19)

of the symbols. Figures III-20 and III-21 combined give a more complete equipment usage for Line 161-20. It may be observed that equipment shown on Figures III-20 and III-21 hardly exhausts the possibilities of equipment application for a 161 kV line. These figures, moreover, indicate the desirability of having both switching and relaying One Line Diagrams except for the simpler substations.

c. Three Line Diagram

d. Electrical Plot Plan

e. Site Preparation

f. Fence Layout

g. Electrical Layouts

h. Structure Erection Diagrams

i. Foundation Layouts

j. Grounding Layout

k. Conduit Layout

l. Control House - Architectural, Equipment, Layout, Lighting, etc.

m. Station Service Diagrams AC and DC

n. Cable Lists and Conduit Lists

   Cables may be listed on a drawing, such as a conduit layout, if the number of cables is not large. On large stations, it generally is desirable to have a separate cable list. A cable identification system should be devised related to the location of one end of a cable and to the function of the cable.

   An alpha-numeric designation often works well. In such a system, C4-3 could be a cable from a circuit breaker at location C4 on a grid system where C designates an equipment row centerline in a series A, B, C, D, etc. and 4, designates a row centerline in a series 1,2,3,4,5,6, etc., at a right angle to centerline C. The -3 could represent a cable for control.

Different arabic numerals could be used for other functions.

o. Bills of Material

As a general rule, all elements of work in a substation should have a list of material. When such lists comprise a multisheet drawing, they are known as Bills of Material. Formats should be devised to include the following information as a minimum:

(1) Identification of substation

(2) Alpha-numeric code name for items that may appear on a construction drawing for identification and location

(3) Adequate description of item

(4) Reference to applicable purchasing document

(5) Quantity of item

(6) Reference to drawing(s) on which item is shown for installation

p. Drawing List

It is recommended that every substation have a drawing list to include, at the Borrower's and Engineer's discretion, manufacturers' drawings, design calculations, Borrower's standard drawings, etc.

q. Control Panels

r. Schematic & Detail Wiring Diagrams

These should be prepared following the guidelines in ANSI Standard Y14.15, "Electrical and Electronic Diagrams."

F. <u>STUDIES</u>

For many substations, it will be necessary to make a number of studies such as feasibility studies, economic comparisons, voltage drop calculations for control and auxiliary power circuits, rigid and strain bus design comparisons, structural design calculations, etc. The results of these studies along with the Calculations should be retained with other documents relating to the particular substation.

APPENDIX

DRAWING CHECKLIST
APPLICABLE TO ALL DRAWINGS

Checker's Initials	Item
________	Drawing is of material satisfactory to Borrower
________	Drawing is of a size satisfactory to Borrower
________	Drawing is identified as satisfactory to Borrower
________	Drafting Practice is in accordance with Chapter III, Section E2
________	All line work and lettering are reproducible
________	The smallest lettering is readable at the smallest proposed reduction size
________	Has consideration been given to overall organization of drawing to minimize field inconvenience?
________	Does the drawing avoid ambiguities, incompleteness, lack of clarity, misleading emphasis, etc? (If a mistake is made in construction it <u>could</u> be that the drawing, although not being wrong, <u>could</u> have been clearer.)
________	Legends, notes, symbols have been carefully reviewed for correctness and completeness
________	Appropriate drawings referenced
________	All changes incorporated as required by Borrower or REA

SWITCHING ONE-LINE DIAGRAM CHECKLIST

Checker's Initials	Item
________	General requirements, applicable to all drawings, have been met
________	Acceptable symbols are used; reference Chapter III, Sec. E 3.b (8)
________	Symbols are arranged, as much as practical, the same as the represented equipment
________	North orientation is the same as Electrical Plot Plan
________	Major equipment numbering scheme meets Borrower's requirements
________	Buses and circuit connections are identified in accordance with Borrower's requirements
________	Vector relations and phasing are shown where pertinent
________	Symbols and line widths are sized so that those for major equipment are more prominent than those for less important equipment
________	Symbols and lettering are so proportioned with respect to each other that the drawing is easy to read
________	Lines representing conductors have widths relative to, though not necessarily in direct proportion to, their current carrying ability
________	All insulated conductors are identified as to number per phase, voltage class, conductor size and material, and insulation type
________	All uninsulated conductors are identified as to number per phase, size and material
________	Substation phasing relative to geographical is shown by a three line detail near the north arrow

SWITCHING ONE-LINE DIAGRAM CHECKLIST (cont'd)

Checker's Initials	Item
________	Reference is made to Electrical Plot Plan and Functional Relaying One-Line Diagram
________	Substation ac service is shown at least to include the transformer(s) and ac service diagram is referenced
________	Any unusual manual switching constraints are enumerated in the Notes
________	Conform to short range and long range requirements of Power Supply Study
________	Conform to requirements of two-year work plan
________	Agrees with conceptual one-line of authorization document
________	Agrees with all other drawings such as Electrical Plot Plan and Electrical Layouts
________	No conflict with major equipment as may have been previously specified or allocated

FUNCTIONAL RELAYING ONE-LINE DIAGRAM CHECKLIST

Checker's Initials	Item
________	General requirements, applicable to all drawings, have been met
________	Arrangement of symbols is as close as practical to that of switching one-line diagram
________	Major equipment identification, conductor identification, and surge arresters are not shown
________	Current transformer polarity marks, overall ratios, and connected ratios are shown
________	All protective relays are shown by appropriately numbered symbolic circles
________	Each device in a current transformer circuit is shown in the same order as the actual wired connection
________	Voltage transformer ratios and secondary winding protection are shown
________	Instrument transformer connection are indicated by appropriate symbolism for delta or wye connections and grounded or ungrounded
________	Reference is made to switching one-line diagrams and control and relay panel front views
________	Lines representing current transformer connection (preferred horizontal) and lines representing potential connections (preferred vertical) contact relay or meter symbols at right angles to each other
________	Arrows are shown near protective relay to indicate direction of fault that calls for circuit breaker tripping
________	Notes have been made covering desired action upon operation of differential, transfer trip, breaker failure relays, etc.

FUNCTIONAL RELAYING ONE-LINE DIAGRAM CHECKLIST (cont'd)

Checker's Initials	Item
________	Legend includes only symbols not covered on switching one-line diagram
________	Appropriate symbolism has been developed for supervisory control, telemetering, communication links, etc.
________	DC auxiliary relays shown
________	Trip and interlock-functions shown

DRAWING CHECKLIST
ELECTRICAL PLOT PLANS

Checker's Initials	Item
________	General requirements, applicable to all drawings, have been met
________	North orientation is same as one-line diagram(s)
________	Agrees with one-line diagram
________	Circuit connection phase conductors and shield wires have been verified with transmission and distribution authorities as to size, material, take-off points, and direction; shielding for direct stroke lightning protection meets required criteria
________	Switching one-line diagrams, electrical layouts, foundation layouts, site preparation, and other pertinent construction drawings are consistent and appropriately referenced

U.S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION
SUBSTATION DESIGN SUMMARY

I. INTRODUCTION

A. GENERAL

1. This summary provides basic information on substation requirements and design.

2. The summary will be updated as the project progresses from initial design to in-service status. In its final form it will be, with supporting and reference documents, a complete record of the substation.

B. BASIC IDENTIFICATION DATA

1. Substation Name ______________________________

2. Borrower's Designation and Name ______________________________

   ____

3. Location ______________________________

4. Summary Prepared by ______________________________

   Date ______________________________

   Revision "A" Prepared by ______________________________

   Date ______________________________

   (As many listings as necessary. Whenever a revision is made, a notation should be entered in the left hand margin-adjacent to the item revised.)

C. SCHEDULE

	Proposed or Record Date
1. Pre-Design (identify documentation of each item for record)	

	Proposed or Record Date
a. Environmental impact statement or brief environmental report	______
b. Site purchase and title clearance	______
c. Topographical survey	______
d. Ambient noise level survey	______
e. Surrounding land use survey	______
f. Soil borings	______
g. Soil resistivity measurement	______
2. Design	
a. One-line diagram and general layout for Borrower's approval	______
b. Detail design for Borrower's approval (List individual areas such as foundations, structures, electrical below grade, electrical above grade, and protective relaying if separate submittals are required.)	______
c. Design complete	______
3. Procurement (itemize as listed below for each set of equipment, material, and hardware)	
a. Specification for Borrower's approval	______
b. Invite bids	______

	Proposed or Record Date
c. Pre-bid meeting with vendors or contractors (sometimes advantageous for major equipment or construction)	
d. Receive bids	
e. Bid opening (usually construction only)	
f. Evaluation of bids	
g. Pre-award meeting (sometimes advantageous with major equipment or construction)	
h. Award contract	
i. Delivery (equipment, material or hardware)	
4. Construction	
a. Begin construction	
b. Complete site grading	
c. Complete drainage	
d. Complete roadways	
e. Complete fence	
f. Begin foundations, conduit, and grounding	
g. Complete below grade	
h. Begin above grade	
i. Complete outdoor yard	
j. Complete control house	

Proposed or Record Date

k. Complete testing (list documents) ______

l. Complete inspection (list documents) ______

m. In-service ______

D. PERMITS AND LICENSES

List all permits and licenses that will be required prior to and during construction. ______

E. REFERENCES

1. Power supply study (identify) ______

2. Two Year Work Plan (identify) ______

3. Conceptual one-line diagram (identify) ______

II. DESIGN CONSIDERATIONS

A. INITIAL AND ULTIMATE REQUIREMENTS

1. Nominal Operating Voltages (itemize as listed below for each voltage)

a. Voltage ______ kV

b. Connection (delta or wye) ______

c. Phase rotation ______

d. Phase displacement with respect to other voltages (leads or lags) ______ ______ kV by ______°

2. Capacity

a. Voltage Transformations (itemize as listed below for each transformation)

(1) Initial

(a) High voltage __________ kV

(b) Low voltage ___________ kV

(c) Capacity __________ MVA

(2) Ultimate (if different than initial)

(a) High voltage __________ kV

(b) Low voltage ___________ kV

(c) Capacity __________ MVA

b. Circuit Connections (itemize as listed below for each connection)

(1) Initial

(a) Voltage __________ kV

(b) Quantity __________

(2) Ultimate

(a) Voltage __________ kV

(b) Quantity __________

c. Bus Configurations (itemize as listed below for each bus)

(1) Initial

(a) Nominal bus voltage __________ kV

(b) Configuration (single bus, sectionalized bus, main and transfer bus, ring bus, breaker-and-a-half, double breaker-double bus)

____

(2) Ultimate

(a) Nominal bus voltage __________ kV

(b) Configuration (single bus, sectionalized bus, main and transfer bus, ring bus, breaker-and-a-half, double breaker-double bus)

____

d. Current Carrying Requirements (itemize as listed below for each bus and circuit connection)

(1) Bus or circuit connection description

____

(2) Nominal voltage __________ kV

(3) Ampacity

(a) Continuous __________ amperes

(b) 24 hour temporary __________ amperes

e. Ultimate Power Supply Fault Conditions

(1) Three phase fault __________ amperes

(2) Phase to phase fault __________ amperes

(3) Phase to ground fault __________ amperes

f. Maximum Permissible Fault Clearing

Time __________ seconds

B. <u>SITE</u>

State any unusual constraints imposed on the design because of site characteristics.

C. <u>ENVIRONMENTAL</u>

1. State that design is in accordance with Environmental Impact Statement (identify) or Brief Environmental Report (identify).

2. Describe, in general, any design measures taken to enhance appearance.

3. State the necessity for any unusual cost items related to public safety.

4. State the rationale for noise contribution.

5. State the expected electrostatic and electromagnetic effects.

6. State the rationale for effluent design. Recommend that a design be made for a plan of action to prevent pollution if this is so indicated.

D. NATURE

1. Weather

   a. State any unusually severe possible local conditions that the substation is not designed to withstand.

   b. State what design measures have been taken with respect to any special local condition.

2. Temperatures

   a. Average annual temperature

      (1) Maximum __________°C (__________°F)

      (2) Minimum __________°C (__________°F)

   b. Highest recorded temperature _____°C (_____°F)

   c. Lowest recorded temperature _____°C (_____°F)

3. Wind and Ice Loading (itemize as listed below for line support structures, equipment support structures, and conductors)

   a. Wind

      (1) Velocity __________km/hr (__________mph)

      (2) Safety factor __________

      (3) Gusts __________km/hr (__________mph)

      (4) Safety factor __________

b. Ice

(1) Thickness __________ cm (__________ in)

(2) Safety factor __________

4. Precipitation

a. Design rainfall

(1) Amount __________ cm/hr (__________ in/hr)

(2) Period __________ hours

(3) Frequency of storm occurence __________

b. Design snowfall

(1) Maximum drift depth _____ m (_____ ft)

c. Electrical storms

(1) Isokeraunic level __________ thunderstorm days per year

d. Humidity

State design measures.

5. Altitude Above Mean Sea Level _____ m (_____ ft)

6. Seismic Risk Zone __________

7. Wildlife Protection

State any unusual measures required.

8. Airborne Foreign Material Protection

State materials protecting against.

III. DOCUMENTS

A. AUTHORIZING DOCUMENT FOR DESIGN

____

____

B. <u>DISTRIBUTION OF DOCUMENTS</u> (itemize as listed below for each document)

1. Document Description ______________________________

2. Name and Address of Recipient

____

____

____

3. Number of Copies ____________________

C. <u>REA PROCEDURES</u> (to be checked with)

1. Name and Address of REA Field Representative

____

____

____

D. <u>PROCUREMENT</u>

1. Major Equipment (itemize as listed below for each major piece of equipment)

a. Description of Equipment ____________________

____

b. Name and Address of Manufacturer

____

____

____

c. Contract number __________________

d. Purchase order number __________________

2. Construction Contracts (itemize as listed below for each contract)

   a. Description of contract ______________________

   ____

   b. Name and Address of Contractor

   ____

   ____

   ____

   c. Contract number __________________

   d. Purchase order number ___________________

3. Equipment Materials, and Hardware (itemize as listed below for each item)

   a. Description of item __________________________

   ____

   b. Name and Address of Manufacturer

   ____

   ____

   ____

   c. Purchase order number ____________________

E. DRAWING LIST OR DRAWING LIST NUMBER

Provide list of drawings or drawing list number.

F. STUDIES

Describe the studies that are required.

IV. PHYSICAL LAYOUT

A. SUBSTATION TYPE (distribution, transmission, switching)

____

B. TYPE OF DESIGN (Borrower's standard, packaged, custom)

____

C. CIRCUIT CONNECTIONS (itemize as listed below for each connection)

1. Overhead Circuits

a. Nominal voltage __________ kV

b. Quantity __________

c. Conductor size, type, and material __________

d. Pull-off elevation __________ m (__________ft)

e. Maximum tension __________ N (__________lb)

(1) Temperature __________°C (__________°F)

(2) Ice thickness __________ cm (__________in)

(3) Wind velocity _____ km/hr (_____mph)

f. Shield wires

(1) Quantity of shield wires per connection ______

(2) Wire size, type, and material __________

(3) Pull-off elevation _____ m (_____ft)

(4) Maximum tension (at same conditions as phase conductors) _______ N (______lb)

5. Underground Circuits

a. Nominal voltage __________ kV

b. Quantity __________

c. Conductor size, type, material, and insulation

____

____

D. DISTRIBUTION SUBSTATIONS (only)

1. Provisions for Mobile Transformer (yes or no) _____

2. Provisions for Mobile Substation (yes or no) _____

3. Provisions for Future Addition of (describe) _____

____

4. Provisions for Source Voltage Change (yes or no) _______

a. Initial voltage __________ kV

b. Ultimate voltage __________ kV

c. Change of (describe) _________________________

____

5. Provisions for Load Voltage Change (yes or no) _________

a. Initial voltage __________ kV

b. Ultimate voltage __________ kV

c. Change of (describe) _________________________

____

E. TRANSMISSION SUBSTATIONS (only)

1. Provisions for Future Addition of (describe) _____

____

2. Provisions for Source Voltage Change (yes or no) _______

a. Initial voltage __________ kV

b. Ultimate voltage __________ kV

c. Change of (describe) _________________________

____

3. Provisions for Load Voltage Change (yes or no) ____

a. Initial voltage __________ kV

b. Ultimate voltage __________ kV

c. Change of (describe) _________________________

____

F. <u>SWITCHING SUBSTATIONS</u> (only)

1. Provisions for Future Addition of (describe) ______

____

2. Provisions for Voltage Change (yes or no) _________

a. Initial voltage __________ kV

b. Ultimate voltage __________ kV

c. Change of (describe) _________________________

____

G. <u>BUS CONFIGURATION</u> (itemize as listed below for each bus)

1. Initial

a. Nominal bus voltage __________ kV

b. Configuration (single bus, sectionalized bus, main and transfer bus, ring bus, breaker-and-a-half, double breaker-double bus) _____________

2. Ultimate (if different than initial)

a. Nominal bus voltage __________ kV

b. Configuration (describe) ____________________

____

H. <u>DIRECT STROKE SHIELDING</u>

1. Shielding Measures (rods, wires, masts) (describe)

____

2. Shielding Angles

a. Angle from vertical for single rod, wire, or mast __________°

b. Angle from vertical for adjacent rods, wires, or masts __________°

I. <u>INSULATORS</u> (itemize as listed below for each voltage)

1. Apparatus Insulators

a. Nominal voltage __________ kV

b. Type (cap and pin or post) __________

c. BIL __________ kV

d. Color __________

e. Cantilever strength _______ N (_______lb)

f. NEMA TR No. (or other description) ___________

____

2. Suspension Insulators

a. Nominal voltage __________ kV

b. Quantity per string __________

c. Color __________

d. M-E strength __________ N (__________lb)

e. ANSI Class (or other description) ____________

____

J. ELECTRICAL CLEARANCES (itemize as listed below for each voltage)

1. Nominal voltage __________ kV

	Rigid Conductors	Non-Rigid Conductors
2. Minimum Metal-to-Metal	______cm(______in)	______cm(______in)
3. Minimum Phase to Grounded Parts	______cm(______in)	______cm(______in)
4. Minimum Phase to Substation Grade	_____m(______ft)	______m(______ft)
5. Minimum Phase to Substation Roadway	______m(______ft)	______m(______ft)
6. Centerline-to-Centerline Phase Spacing	______m(______ft)	______m(______ft)

K. BUS AND ELECTRICAL CONNECTIONS (itemize as listed below for each case)

1. Nominal Voltage __________ kV

2. Type of Connection (describe) _____________________

3. Rigid Conductors (clamp, bolted, welded) __________

4. Non-Rigid Conductors (clamp, compression, welded) ______________

5. Fasteners (describe) ______________________________

____

L. RIGID BUSES (itemize as listed below for each bus)

1. Conductor Size, Type, and Material ________________

2. Design Short Circuit Current (three phase symmetrical) __________ rms amperes

3. Wind and Ice Loading (see Section II.D.3)

4. Support Insulator Spacing __________m (__________ft)

5. Factor of Safety for Support Insulators ___________

6. Maximum Conductor Sag Without Ice _________________

7. Maximum Conductor Sag With Ice ____________________

8. Measures for Prevention of Aeolian Vibration ______

____

9. Provisions for Conductor Expansion ________________

____

M. STRAIN BUSES (itemize as listed below for each bus)

1. Conductor Size, Type, Stranding, and Material

____

2. Wind and Ice Loading (see Section II.D.3)

3. Span Length __________ m (__________ft)

4. Factor of Safety for Suspension Insulators ________

5. Sag and Tension at Maximum Loading Conditions ______ m (______ft) sag at ______ N (______lb) tension

6. Sag and Tension at 25°C (77°F) ______ m (______ft) sag at ______ N (______lb) tension

7. Sag and Tension at 70°C (167°F) ______ m (______ft) sag at ______ N (______lb) tension

V. MAJOR EQUIPMENT (itemize as listed below for each different component)

A. POWER TRANSFORMERS

1. Type (auto, multi-winding, 3-phase, 1-phase) ______

2. Quantity __________

3. Dielectric (oil, air, or gas) __________

4. Rating ______/______/______ MVA

5. Cooling (OA, OA/FA, OA/FA/FA, OA/FOA, OA/FA/FOA, OA/FOA/FOA) ____________________

6. Average Winding Temperature Rise (55°C, 65°C) _____

7. Primary Voltage __________ kV

   a. No-load taps ________________

8. Secondary Voltage __________ kV

   a. No-load taps ________________

9. Tertiary Voltage __________ kV

   a. No-load taps ________________

10. Load-Tap-Changer (LTC)

    a. Percent above and below nominal voltage ______

    b. Winding (primary or secondary) _______________

11. BIL

    a. Primary winding __________ kV

    b. Secondary winding __________ kV

    c. Tertiary winding __________ kV

B. <u>POWER CIRCUIT BREAKERS</u>

1. Type (dead tank or live tank) _____________________

2. Quantity __________

3. Interrupting Medium (oil, air, gas, vacuum) _______

4. Nominal Voltage __________ kV

5. Maximum Voltage __________ kV

6. Rated Voltage Range Factor (K) __________

7. Continuous Current __________ rms amperes

8. Short-Circuit Current at Rated Maximum Voltage __________ rms amperes

9. Maximum Symmetrical Interrupting Capability __________ rms amperes

10. 3-Second Short Time Current Capability __________ rms amperes

11. Closing and Latching Capability _______ rms amperes

12. Interrupting Time __________ cycles

13. Type of Operating Mechanism (solenoid, motor, pneumohydraulic, pneumatic, motor-changed spring, manual-charged spring, manual) ____________________________

14. Control Power Voltage __________ VAC __________ VDC

15. Auxiliary Power Voltage __________ VAC

C. <u>METAL-CLAD SWITCHGEAR</u>

1. Nominal Voltage __________ kV

2. Indoor or Outdoor __________

3. Switching Scheme (describe) ________________________

____

4. Continuous Current __________ amperes

5. Maximum RMS Momentary Current __________ ka

6. Circuit Breaker Interrupting Capability ______ amperes

D. <u>SUBSTATION VOLTAGE REGULATORS</u>

1. Type (step or induction, single or three phase)

____

2. Quantity __________

3. Nominal Voltage __________ kV

4. Rating _______ kVA

5. Percent Regulation + __________%, - __________%

E. SHUNT CAPACITOR EQUIPMENT

1. Type (open rack or housed) ________________________

2. Quantity __________

3. Nominal Voltage __________ kV

4. Bank Rating __________kVAR

5. Individual Units

   a. Voltage __________ kV

   b. Rating __________ kVAR

6. Connection (delta, wye, grounded wye, double wye)

   ____

F. AIR SWITCHES

1. Type (disconnecting, grounding, horn-gap, interruptor, selector) _______________________________

2. Quantity __________

3. Construction (vertical break, double break, tilting insulator, side break, center break, vertical reach)

   ____

4. Operating Mechanism (hook stick, manual mechanism, motor mechanism) __________________________________

5. Poles (single or three) ___________________

6. Nominal Voltage __________ kV

7. Continuous Current __________ amperes

8. Momentary Current __________ amperes

9. Interrupting Current __________ amperes

G. <u>SURGE ARRESTERS</u>

1. Type (station, intermediate, distribution) ________

2. Quantity __________

3. Voltage Rating _________ kV

4. Nominal System Voltage __________ kV

5. For Protection of (describe) ______________________

____

H. <u>AUTOMATIC CIRCUIT RECLOSERS</u>

1. Quantity __________

2. Nominal Voltage __________ kV

3. Continuous Current __________ amperes

4. Interrupting Current __________ amperes

5. Single or Three Phase __________

6. Interrupting Medium (oil, vacuum) __________

7. Control (Hydraulic or electronic) __________

8. Coil Tripping (series, non-series) __________

9. Closing (spring, solenoid, motor) __________

10. Minimum Tripping Current __________ amperes

11. Operational Sequence to Lockout (describe)

____

I. <u>CURRENT TRANSFORMERS</u>

1. Type (bar, window, bushing, other) __________

2. Quantity __________

3. Nominal Voltage __________ kV

4. BIL _________ kV

5. Ratio(s) __________________

6. Accuracy (metering or relaying) __________

7. Accuracy Class __________

8. Burden __________

J. VOLTAGE TRANSFORMERS

1. Type (cascade, grounded neutral, insulated neutral, single high voltage line terminal, double high voltage line terminal) ____________________________________

2. Quantity __________

3. Nominal Voltage __________ kV

4. BIL __________ kV

5. Ratio(s) __________

6. Accuracy __________

7. Burden __________

K. COUPLING CAPACITORS AND COUPLING CAPACITOR VOLTAGE TRANSFORMERS

1. Type (CC or CCVT) __________

2. Quantity __________

3. Nominal Voltage __________ kV

4. BIL __________ kV

5. Capacitance __________ henries

6. Carrier Accessories (yes or no) __________

7. Voltage Transformer (yes or no) __________

    a. Ratio(s) __________

L. MOBILE UNITS

1. Type (transformer, substation) __________

2. Quantity __________

3. Primary Voltage __________ kV

4. Secondary Voltage __________ kV

5. Capacity ___________ MVA

6. Accessories (list and describe) ___________________

____

____

____

VI. SITE

A. GENERAL

1. Yard Type (flat, sloped, stepped) __________

2. Nominal Finished Grade Elevation(s)

    __________ m (__________ft) with

    __________ % slope

3. Topographical Drawing Reference __________

4. Soil Boring Reference __________

B. DRAINAGE

1. Type of System (surface or closed) __________

2. Design Basis (see Section II.D.4)

3. Time for Run-Off from Remotest Part of Drainage Area __________ hours

C. EARTHWORK

1. Excess Top Soil __________ m^3 (__________yd^3)

2. Fill Required __________ m^3 (__________yd^3)

3. Earth to be Moved Exclusive of Excess Top Soil

   __________ m^3 (__________yd^3)

D. ROADS (itemize as listed below for each access road, interior road, and railroad)

1. Length __________ m (__________ft)

2. Width __________ m (__________ft)

3. Maximum Grade __________%

4. Minimum Inside Curve Radius

   __________ m (__________ft)

5. Base Course __________

6. Wearing Course __________

7. Maximum Equipment Load _______kg/axle (______lb/axle)

E. EROSION PROTECTION

State basic description.

F. YARD SURFACING MATERIAL

1. Material

   a. Type __________

   b. Size __________

2. Material Placement

   a. Area ______________________________

   b. Layer depth __________ cm (__________in)

G. SECURITY FENCE

1. Height __________ m (__________ft)

2. Fabric Gauge __________

3. Fabric Material __________

4. Gates (itemize as listed below for each size gate)

   a. Size __________ m (__________ft)

   b. Quantity __________

5. Depth of Post Footing Holes _______ m (______ft)

VII. STRUCTURES

A. LINE SUPPORT STRUCTURES

1. Material ____________________

2. Protective Coating or Treatment ____________________

3. Loading Criteria

   a. Conductors _______ N (_______lb) per phase

   b. Shield wires _______ N (_______lb) per wire

   c. Equipment weight __________ kg (__________lb)

   d. Wind and ice loads (see Section II.D.3)

   e. Seismic (describe) ____________________________

   ____

4. Overload Factor _______________________

5. Unit Stress Limit _____________________

6. Deflection Limits _____________________

7. Fasteners (describe) ______________________________

____

B. <u>EQUIPMENT SUPPORT STRUCTURES</u>

1. Material ______________________

2. Protective Coating or Treatment ________________

3. Loading Criteria

   a. Equipment weight _________ kg (_________lb)

   b. Short circuit force _____ N/m (_____lb/ft)

   c. Wind and ice loads (see Section II.D.3)

   d. Seismic (describe) ________________________

   ____

4. Unit Stress Limit ______________________

5. Deflection Limits ______________________

6. Rigidity Considerations ________________________

   ____

7. Fasteners (describe) ___________________________

   ____

VIII. FOUNDATIONS

A. <u>SOIL</u>

1. Type __________________

2. Allowable Soil Bearing Pressure _____ N/m^2 (___psf)

3. Describe Other Soil Capability Limitations _______

   ____

   ____

4. Ground Water Elevation _________ m (_________ft)

B. DESCRIPTION OF CONCRETE

1. Type ______________________________

2. Minimum 28 Day Compressure Strength

   __________ N/cm^2 (__________psi)

3. Depth Below Grade to Withstand Frost

   __________ m (__________ft)

C. DESCRIPTION OF REINFORCING BAR

Describe the reinforcing bar used in each type of foundation.

D. OIL POLLUTION ABATEMENT

Describe methods for oil pollution abatement.

E. FOUNDATION TYPES

Describe each type of foundation (augered pin, spread footing, slab) and its function.

IX. GROUNDING

A. Total Ultimate Fault Current __________ amperes

B. Portion of Ultimate Fault Current Which Can Flow Through Earth into Grounding Grid __________ amperes (total current less that which flows to system neutral through shield wires)

C. Shock Duration (fault clearing time) __________ seconds

D. Average Earth Resistivity __________ohm-meters

1. Depth __________ cm (__________in)

2. Date Measured __________

E. Grid Conductor

1. Size __________

2. Length __________ m (__________ft)

F. Ground Rods

1. Quantity __________

2. Size

a. Diameter __________ cm (__________in)

b. Length __________ m (__________ft)

G. Allowable Voltages

1. E_{step} __________ volts

2. E_{touch} __________ volts

3. Surface Resistivity __________ ohm-meters

H. Calculated voltages

1. E_{step} __________ volts

2. E_{touch} __________ volts

3. If calculated voltages are much less than allowable voltages, explain

____

____

____

I. Substation Area __________ m^2 (__________ft^2)

J. Peripheral Ground Wire (describe) ______________________

____

____

X. INSULATED CABLES AND RACEWAYS

A. <u>CABLES</u> (itemize as listed below for each type of cable)

1. Type (control or power) __________

2. Voltage Rating __________ volts

3. Conductor Size, Type, and Material ________________

____

4. Number of Conductors _________________

5. Quantity __________ m (___________ft)

6. Insulation

   a. Type (PVC, PE, PVC(I), XLPE(I), SLPE, RULAN)

   ____

   b. Thickness __________ mils

7. Jacket

   a. Type (neoprene or PVC)

   b. Thickness over each conductor __________ mils

   c. Thickness over entire cable __________ mils

B. <u>RACEWAYS</u> (itemize as listed below for each type of raceway)

1. Conduit

   a. Material _________________________

   b. Size __________ cm (__________in)

2. Duct Bank

   a. Size

      (1) Width __________ m (__________ft)

      (2) Depth __________ m (__________ft)

      (3) Number of conduits

         (a) Width __________

         (b) Depth __________

(4) Size of conduits _______ cm (_______ in)

3. Cable Trench

a. Type (concrete block, cast in place concrete, or precast concrete) ________________________

b. Width __________ cm (__________ in)

c. Depth __________ cm (__________ in)

XI. CORROSION

A. State Rationale for the Provision (or lack of it) of a Cathodic Protection System

B. <u>CATHODIC PROTECTION SYSTEM</u>

1. Summary of Soil Resistivity Survey

____

____

____

____

2. Summary of PH Survey

____

____

____

____

3. Basic Description of Protection System

____

____

____

____

XII. PROTECTIVE RELAYING

A. State the General Philosophy of the Protective Relaying Systems: Coordination Required With Other Parts of the System, Expected Fault Currents for Various Conditions, Speed of Interruption Sought for Various Cases, etc.

B. TRANSMISSION LINE PROTECTION (itemize as listed below for each line)

1. Line Destination or Description ____________

2. Nominal Voltage ________ kV

3. Protection Scheme (phase comparison, directional comparison, direct underreach, permissive underreach, permissive overreach, overcurrent-describe) ______

____

4. Automatic Reclosing (yes or no-describe) ________

____

5. Relays (list) ____________________________

____

C. TRANSFORMER AND REACTOR PROTECTION (itemize as listed below for each transformer and reactor)

1. Transformer or Reactor Number or Description _____

2. Nominal Voltages (Primary/tertiary/secondary)

________/________/________ kV

3. Protection Scheme (differential, sudden pressure, directional phase distance, ground overcurrent-describe)

____

____

4. Relays (list) ____________________________

____

D. BUS PROTECTION (itemize as listed below for each bus)

1. Bus Number or Description ____________________

2. Nominal Voltage ________ kV

3. Protection Scheme (current differential, voltage differential-describe) ____________________

____

4. Relays (list) ____________________

____

E. BREAKER FAILURE PROTECTION

1. Where Applied (describe) ____________________

____

2. Relays (list) ____________________

____

F. DISTRIBUTION LINE PROTECTION (itemize as listed below for each line)

1. Line Destination or Description ____________________

2. Nominal Voltage ________ kV

3. Protection Scheme (overcurrent relaying, automatic circuit reclosers, sectionalizers, fuses-describe)

____

4. Relays and Equipment (list) ____________________

____

XIII. INSTRUMENTS, TRANSDUCER, AND METERS

Describe metering systems and list equipment for each system.

XIV. AC AND DC AUXILIARY SYSTEMS

A. AC SYSTEM

1. Connected AC Load __________ kVA

2. Overall Demand Factor ____________%

3. Auxiliary Transformer

   a. Rating __________ kVA

   b. Voltage (primary/secondary) ________/________ kV

4. Normal Source (describe) __________________________

   ____

5. Alternate Source (describe) _______________________

   ____

6. Auxiliary System Voltage (480/277 volts, wye connected, three phase, four wire; 208/120 volts, wye connected, three phase, four wire; 240/120 volts, delta connected, three phase, four wire; 240/120 volts, open delta connected, three phase, four wire; 240/120 volts, single phase, three wire) __________

   ____

7. Transfer Switch (describe) ________________________

   ____

8. Asymmetrical Fault Current at Main Panelboard or Switchboards __________ amperes

9. Panelboards and Switchboards (describe) ___________

   ____

   ____

10. Outdoor Lighting

    a. Objective (describe) __________________________

       ____

b. Luminaires (describe) ______________________

____

c. Switching method (describe) ________________

____

B. <u>DC SYSTEM</u>

1. DC System Loads (list) _____________________

____

2. Nominal Voltage __________ volts

3. Battery

a. Ampere-hours __________________

b. Number of cells _______________

4. Battery Charger (describe) _________________

____

XV. CONTROL HOUSE

A. <u>INSIDE DIMENSIONS</u>

1. Length __________ m (__________ft)

2. Width __________ m (__________ft)

3. Clear Height __________ m (__________ft)

B. <u>BASEMENT</u> (yes or no) _______________

C. <u>FOUNDATION</u>

1. Footings

a. Width __________ cm (__________in)

b. Depth __________ m (__________ft)

c. Depth below grade _______ m (_______ft)

2. Foundation Walls

a. Type (cast in place concrete or concrete block)

____

b. Perimeter Insulation (yes or no) ____________

1. Type ______________________

2. Thickness _________ cm (_________in)

3. Location (inside or outside of walls)

____

3. Floor

a. Thickness _________ cm (_________in)

b. Reinforcing (describe) ______________________

____

c. Cast in Concrete Cable Trench (yes or no) (describe)

____

____

D. <u>SUPERSTRUCTURE</u>

1. Type (pre-engineered metal or concrete block) _____

____

2. Roof Type (precast, prestressed concrete panels or steel joists and steel decks) ____________________

3. Doors (itemize as listed below for each door size)

a. Size _______ cm (_______in) x _______ cm (_________in)

b. Quantity _________

4. Windows (itemize as listed below for each window size)

   a. Size _______ cm (_______in) x _______ cm (_________in)

   b. Quantity _________

E. CONTROL PANELS

1. Type (single, double, or duplex) ________________

2. Function (list each panel) ______________________

   ____

3. Size _________ cm (_________in) x _________ cm (_________in)

F. CABLE TRAYS

1. Size _________ cm (_________in)

2. Method of Support (describe) ____________________

   ____

G. LIGHTING

1. Average Illumination _________ lumens/m^2 (_________ lumens/ft^2)

2. Luminaires (describe) __________________________

   ____

   ____

3. Emergency lighting (describe) ___________________

   ____

H. <u>AIR CONDITIONING EQUIPMENT</u>

1. Number of Units ____________________

2. Type of Units ______________________

3. Rating _________________

I. <u>HEATING EQUIPMENT</u>

1. Number of Units _____________________

2. Type of Units _______________________

3. Rating __________________________

XVI. COMMUNICATIONS

Describe the communications systems.

CHAPTER IV - PHYSICAL LAYOUT

A. INTRODUCTION

This chapter presents general information concerning the design of the substation physical arrangement. It describes various types of substations, illustrates typical layouts, and presents guidelines to be used during the detail design. Information concerning insulation, electrical clearances, bare conductors, substation bus design, and the application of mobile transformers and mobile substations is included.

B. LAYOUT CONSIDERATIONS

1. Initial Design Parameters

A careful analysis of basic parameters establishing the purposes and design criteria for the substation must precede the detail design. Much of this information can be found on the Substation Design Summary Form. In addition, circuit quantities, configurations, and ratings, system and equipment protective relay schemes, the necessity for specialized equipment (such as capacitor banks, current limiting reactors and neutral grounding devices), details of surge protection equipment, and requirements for direct stroke protection should be considered.

2. Selection of Switching Scheme

The power system as a whole must be considered when deciding the substation switching scheme. Future system growth based on long range forecasts may indicate the necessity for an economical, basic arrangement initially with possible future conversion to a more sophisticated scheme as the number of circuits increases. Important circuits may require additional protection or redundant supply. Equipment maintenance requirements may necessitate bypassing facilities to enable circuit operation during maintenance periods. Since the equipment that can be out of service for maintenance or during faults without sacrificing system operation depends upon alternate supplies and duplication of circuits, the flexibility of the switching scheme is often one of the most important selection criteria. Large substations with many circuits handling great amounts of power must have high degrees of both flexibility and reliability to continue service without interruption during the most undesirable conditions. Since flexibility and reliability are directly proportional to cost, the ultimate configuration must be the result of a compromise.

3. Substation Expansion

Frequently, after initial substation construction, requirements change, and plans for the ultimate capabilities of the substation are altered. As a result, expansion of the substation facilities may deviate from the anticipated initial plan. To accommodate unforeseen future system modifications, the flexibility of the arrangement should be considered. Since a typical substation can be expected to continue in service for an indefinite time, maintaining maximum flexibility throughout each stage of expansion will ensure the least costly and most efficient use of the facilities during the service period.

To facilitate future expansion, the initial design should be arranged to accommodate all requirements of a current long range system forecast. The site should be as large as practical to allow for future development. Large areas more readily allow for changes in the basic substation configuration and switching scheme should future conditions so dictate. At least one and preferably both ends of all major buses should be left open for future expansion. When a basic initial arrangement is planned, placement of equipment should consider future expansion of the substation into a more complex, reliable and flexible configuration. Frequently, additional switches, switch stands, and bus supports are installed initially to facilitate future expansion.

4. Substation Profile

The profile of substation structures and equipment has become an increasingly important aspect to consider in substation layout. In the past, large lattice and box type structures supporting overhead strain buses were commonly used. Conventional high profile construction is still used somewhat today, particularly for low voltage distribution substations and in areas with natural environmental shielding. However, many substations currently being designed and constructed use low profile structures and rigid bus work.

Low profile construction generally uses lower structures with a minimum number of members for support. Larger pieces of equipment, such as power transformers and power circuit breakers, have become smaller over the years. Consequently, the substations are considered less obtrusive overall. The height limitations causing the use of low profile construction sometimes result in arrangements of increased area, particularly for the lower voltage levels. Generally, the advantages of easier equipment operation and maintenance due to reduced equipment sizes and effective locations make up for the expense of purchasing somewhat larger sites.

5. Underground Circuits

An effective method to improve substation appearance is to install circuits underground as they leave the substation. Low profile construction using lower structures with fewer support members lends itself toward the use of underground circuits. Undergrounding can similarly improve the appearance of substations with larger structures by reducing the size of some of the large supporting structures or eliminating them altogether.

6. Equipment Removal

Substation arrangements must include adequate space for the installation and possible removal of large equipment such as power transformers and power circuit breakers. Buses, particularly in low profile arrangements, even when at acceptable operating elevations, can block the removal of equipment. Consequently, it is important to consider equipment removal routes during the structure layout. Often the most desirable arrangement has the main buses at higher elevations than the buses and equipment in the substation bays. In this way, the main buses will not block the removal of equipment located in the substation interior.

Removable bus sections can also be provided to permit movement of large equipment. This, however, requires bus deenergization during the procedure.

Bay spacing must be carefully evaluated during layout to allow for removal of equipment. In multi-bay configurations, it is common to limit the number of bays to two before increasing the bay center-to-center spacing. This allows equipment to be removed from a bay to the side and provides additional space for moving the equipment between this bay and an adjacent bay, as diagrammed in Figure IV-1.

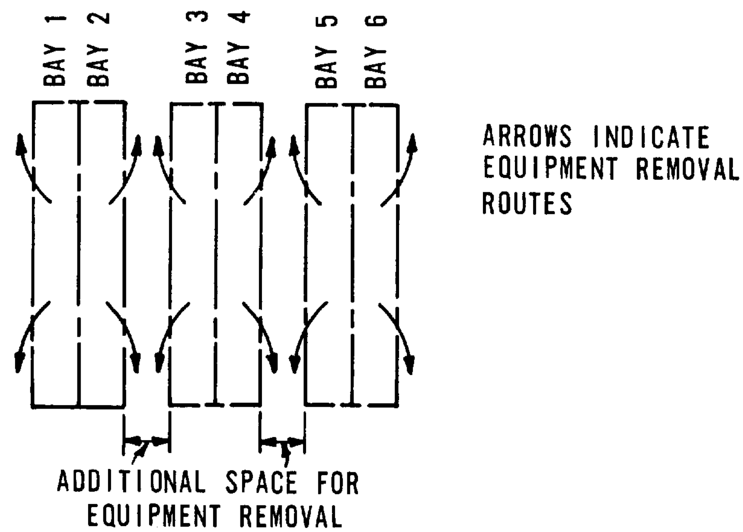


FIGURE IV-1 SUBSTATION PLAN VIEW SHOWING SPACE FOR EQUIPMENT REMOVAL

C. DISTRIBUTION SUBSTATIONS

1. Introduction

Distribution substations are usually characterized by voltages up to 138 kV on the primary side and 12.5Y/7.2kV or 24.9Y/14.4kV on the secondary side.

In recent years, the trend has been toward increasing system voltages. It is becoming more common to eliminate the intermediate transmission substations and directly reduce the transmission voltages to primary distribution levels. The distribution substations discussed are generally limited to the traditional type characterized by simple bus arrangements and minimal equipment. However, the arrangements can be expanded for use in larger distribution substations with higher voltages.

2. Basic Distribution Substation

Figure IV-2 is a one-line diagram for a basic distribution substation. Depending on the load being served, it is possible that initial construction may be limited to one distribution circuit.

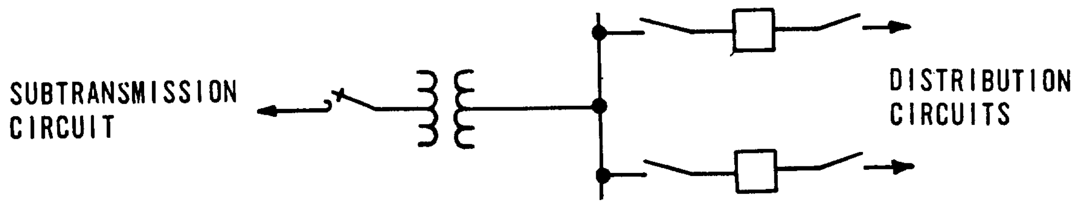


FIGURE IV-2 BASIC DISTRIBUTION SUBSTATION

The subtransmission circuit enters the substation through a primary disconnect switch used principally to isolate the substation from the subtransmission system for maintenance or when replacement of substation equipment is required. It is usually of the three pole, single throw, group operated type.

The power transformers commonly used in this application are two winding type and may be single or three phase units. In new substations and when replacing transformers or increasing transformer capacity, the trend has been toward using three phase transformers. In configurations using single phase transformers, a fourth transformer should be added as a spare. Use of three phase transformers results in a neater and less cluttered arrangement. However, since failure of a three phase transformer necessitates loss of the substation, the overall design layout should provide facilities for the rapid installation of a mobile transformer or a mobile substation.

The two primary distribution feeders of the substation illustrated in Figure IV-2 are protected by either power circuit breakers or automatic circuit reclosers. Disconnect switches on both the source and load sides permit isolation during maintenance or other periods when complete de-energization is required. The switches can be either single pole, single throw, hook stick operated or three pole, single throw, group operated, depending on the arrangement.

3. Transformer Primary Protective Devices

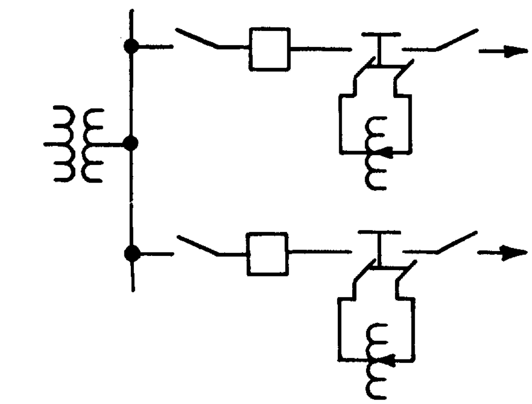
To prevent equipment damage as a result of abnormal conditions such as transformer or low voltage bus faults, protective devices are generally provided on the primary side of the transformer. These devices may also serve as primary disconnects to enable isolation from the transmission system.

Several types of devices are available, including power fuses, circuit breakers, circuit switchers, and vacuum interrupters. Selection of the type of device is based on the voltage, short circuit conditions, and transformer capacity.

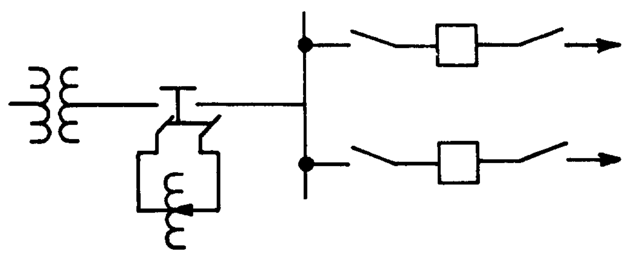
4. Voltage Regulation

To maintain voltage at a uniform level, voltage regulation equipment is usually required in rural distribution substations. The voltage can be regulated by using either feeder or bus regulation. Feeder regulation may be used in multi-circuit distribution substations, where the circuits are very diverse in load characteristics. With feeder regulation, the voltage of each distribution circuit can be individually maintained to conform to the load characteristics. Bus regulation may be used in rural distribution substations, where the distribution feeders have similar load characteristics. Bus voltage may be controlled by using power transformers with load tap changing mechanisms, single or three phase voltage regulators, or switched capacitor banks.

To permit voltage regulator maintenance without feeder or bus de-energization, bypass facilities are provided as illustrated in Figure IV-3.



FEEDER REGULATION



BUS REGULATION

FIGURE IV-3 VOLTAGE REGULATOR BYPASS ARRANGEMENTS

The switches normally used for regulator bypassing automatically combine all switching operations and perform them in the correct operating sequence. Each combined switch can usually be installed in the same space as one single pole disconnect switch.

For a detailed discussion concerning the application of voltage regulators, See REA Bulletin 169-27.

5. Circuit Breaker/Recloser Bypass Facilities

Bypass facilities permit circuit breaker or recloser maintenance or repair without circuit de-energization. Figure IV-4 illustrates a typical bypass arrangement.

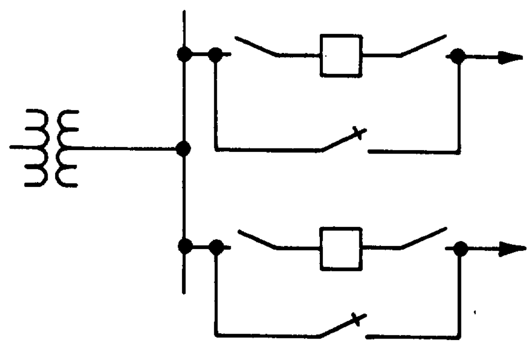


FIGURE IV-4 TYPICAL CIRCUIT BREAKER/ RECLOSER BYPASS ARRANGEMENT

The bypass switches usually consist of three independently operated hook stick switches, but a three pole group operated switch can also be used. In some applications, it may be desirable to combine some of the switches to facilitate installation. Figure IV-5 illustrates one possible configuration.

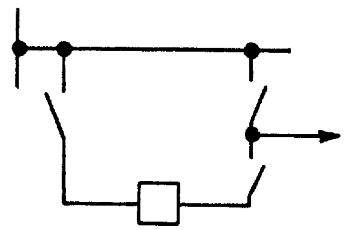


FIGURE IV-5 USE OF TANDEM SWITCHES FOR CIRCUIT BREAKER/RECLOSER BYPASSING

In this configuration, a tandem switch is used to combine the bypass switch and the load side disconnect switch onto a single switch base. The combined switch can be installed in nearly the same space as one single pole disconnect switch.

To provide circuit protection during bypassing, the bypass switch can be replaced by a fuse.

6. Surge Arresters

Transformers, regulators, and other substation equipment are particularly sensitive to transient overvoltages and are required by the National Electrical Safety Code to have surge protection.

For the highest degree of equipment protection, the arresters should be installed as close as practical to the equipment being protected. In most instances, power transformers can be furnished with surge arrester mounting brackets to facilitate installation. Separate arrester stands can also be used, or the arresters can be installed on adjacent switching structures. For voltage regulator applications, the surge arresters are normally installed directly on the regulator tanks.

When power transformers are protected by fuses, transformer surge arresters should be connected on the line side of the fuses, as close as practical to the power transformers.

7. Enclosed Equipment

In certain applications, particularly when space is at a premium, use of switchgear, unit substations, or partially enclosed equipment should be considered. Switchgear is a name commonly used in referring to groupings of switching equipment contained in metal enclosures. All circuit breakers, metering and control equipment, and interconnecting buswork are contained inside the enclosures.

A unit substation consists of switchgear electrically and mechanically connected to at least one power transformer. Various arrangements of power transformers and switchgear equipment are available to suit individual requirements.

Use of switchgear, unit substations, and other types of enclosed equipment eliminates the need for extensive field construction, since most of the equipment is preassembled by the manufacturer or supplier. Depending on the configuration, the equipment may be shipped completely assembled or in sections to be connected together at the job site. Feeders are normally installed underground from the switchgear compartments.

Partial enclosure of some of the low voltage distribution equipment can be implemented to improve the appearance of the substation. The equipment can be furnished in modular form to facilitate installation. Interconnections between modules are usually underground.

D. TRANSMISSION SUBSTATIONS

1. Introduction

Transmission substations are usually characterized by primary and secondary voltages of 69 kV or higher. Since one transmission substation may supply several distribution substations and large loads, reliability of service and flexibility of operation are extremely important. Facilities normally allow equipment maintenance without circuit interruption. Multiple bus arrangements and extensive use of circuit breakers for switching provide added system flexibility.

2. Basic Transmission Substation

Figure IV-6 is a one-line diagram for a basic transmission substation. Depending on system requirements, initial substation construction may be limited to one power transformer and one subtransmission circuit.

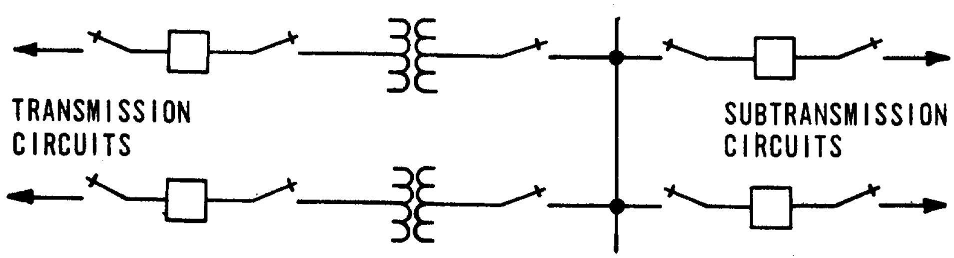


FIGURE IV-6 BASIC TRANSMISSION SUBSTATION

Power circuit breakers are included in the two transmission circuits to help prevent complete substation shutdown for line faults. The circuit breakers have disconnect switches on both source and load sides to permit isolation during maintenance or other periods requiring complete de-energization. These switches are normally of the three pole, single throw, group operated type, mounted on separate stands.

The power transformers commonly used are three phase autotransformers usually with tertiary windings. The disconnect switches on the low voltage sides of the power transformers allow de-energization of one transformer while maintaining service to both low voltage circuits from the other transformer.

The low voltage or secondary section of the substation illustrated in Figure IV-6 consists of two subtransmission feeders protected by power circuit breakers. Disconnect switches on both the source and load sides permit isolation during maintenance or other periods when complete de-energization is required. The switches are normally of the three pole, single throw, group operated type, but can be of the single pole, single throw, hook stick operated type, depending on the voltage and arrangement. Hook stick operated switches usually are not considered above 69 kV.

3. Circuit Breaker Bypass Facilities

Bypass facilities can be provided for the power circuit breakers to permit maintenance without circuit de-energization. Figure IV-7 illustrates a typical arrangement.

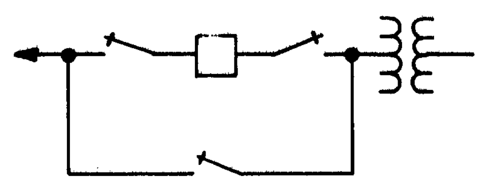


FIGURE IV-7 TYPICAL CIRCUIT BREAKER BYPASS ARRANGEMENT

The bypass facilities normally consist of three independent three pole, single throw, group operated switches. The circuit breaker disconnect switches may be of the single pole, single throw, hook stick operated type, depending on system voltage and bus configuration.

In most cases bypassing circuit breakers removes normal relay protection since the circuit breaker current transformers are also removed from service. The overall protection scheme must be designed to provide for this situation.

4. Surge Arresters

Because of the desire for high reliability and the high cost of equipment replacement, surge arresters are installed in various positions in transmission substations. Since the power transformers are particularly sensitive to overvoltages, they normally have arresters on each phase of both the primary and secondary.

The highest degree of equipment protection occurs with the surge arresters located as close as possible to the equipment to be protected. Power transformers can usually be furnished with arrester mounting brackets adjacent to the transformer bushings.

Occasionally, surge arresters or other surge protective equipment are located at the line entrances and exits. In these instances, it is best to locate the arresters or other protective equipment on the line side of the substation equipment to be protected to limit the lightning and switching surges to acceptable levels as they enter the substation.

5. Carrier Equipment

Line traps, coupling capacitor voltage transformers and associated accessories are used when relaying or communications systems dictate use of carrier equipment for signal transmission to remote terminals. Normally, the line traps and coupling capacitor voltage transformers are installed on separate stands located near the circuit entrance positions in the substations. In some instances, the two pieces of equipment may be mounted on a common structure or stand, depending on the arrangement. The particular relaying and communications schemes being used on the circuit will dictate the number of phases containing line traps and coupling capacitor voltage transformers.

6. Voltage Transformers

Voltage transformers are used in conjunction with the circuit and equipment protection and metering schemes. They are normally mounted on individual or three position stands. Depending on the bus configuration and the relaying schemes, the voltage transformers may be positioned near the circuit entrance positions or adjacent to the buses.

It is usually desirable to provide a method for disconnecting the voltage transformers. One possible method is to install the primary connections to the appropriate buses by using disconnectable clamps. In arrangements using voltage transformers at the circuit positions, they can be positioned to allow de-energization by opening the power circuit breaker and the line disconnect switches.

7. Current Transformers

Current transformers used in both relaying and metering schemes can usually be located inside major equipment such as power circuit breakers and power transformers. These current transformers are normally multi-ratio bushing type and so do not require special mounting provisions. In some cases, separately mounted current transformers may be required, and they are usually installed on individual stands, located as required.

8. Grounding Switches

Manually operated grounding switches are frequently used to ground incoming circuits during maintenance or other out-of-service periods. These switches can be separately mounted or, as is usually the case, can be furnished as part of the circuit disconnect switches. The switches can then be interlocked in such a way as to prevent both from being closed simultaneously.

High speed grounding switches are sometimes used in power transformer protection schemes to initiate tripping of remote circuit breakers during transformer faults. As with manually operated grounding switches, high speed grounding switches can be separately mounted or can be furnished as part of group operated disconnect switches. High speed grounding switches are normally installed on one phase only.

E. SWITCHING SUBSTATIONS

1. Introduction

Switching substations do not change system voltage from one level to another and therefore do not contain power transformers. Switching substations usually operate at subtransmission or transmission voltage levels.

Depending on system voltage, the equipment types and characteristics used in switching substations are identical to those used in transmission substations.

2. Basic Switching Substation

Figure IV-8 is a one-line diagram for a basic switching substation with three terminals.

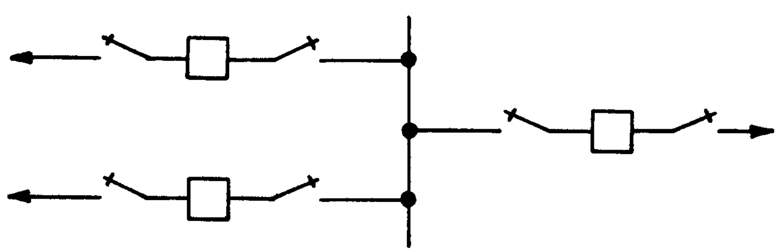


FIGURE IV-8 BASIC SWITCHING SUBSTATION

Power circuit breakers in the three circuits help prevent complete substation shutdown for line faults. The circuit breakers have disconnect switches on both source and load sides to permit isolation during maintenance or other periods requiring complete de-energization. Depending on substation voltage and bus configuration, the switches may be of the three pole, single throw, group operated type or of the single pole, single throw, hook stick operated type. Hook stick operated switches usually are not considered above 69 kV.

Bypass facilities can be provided to allow circuit breaker maintenance without de-energizing the circuit. Figure IV-9 illustrates a typical bypass arrangement.

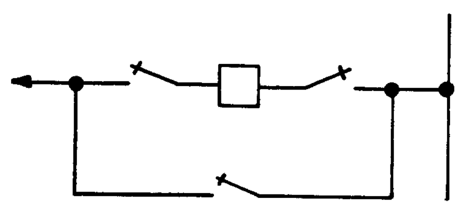


FIGURE IV-9 TYPICAL CIRCUIT BREAKER BYPASS ARRANGEMENT

The bypass facilities may consist of three independent three pole, single throw, group operated switches; single pole, single throw, hook stick operated switches; or a combination of the two types, depending on system voltage and bus configuration.

3. Surge Arresters

Surge arresters or other surge protective equipment may be installed either on the line positions or on the substation buses to protect against excessive lightning or switching surges.

A comparison of the costs of the surge protection equipment to the frequency and extent of possible equipment damage can be evaluated to determine the desirability of the protective equipment. Possible circuit or substation outages as a result of the unprotected surges should be considered.

F. TYPICAL BUS CONFIGURATIONS

1. General

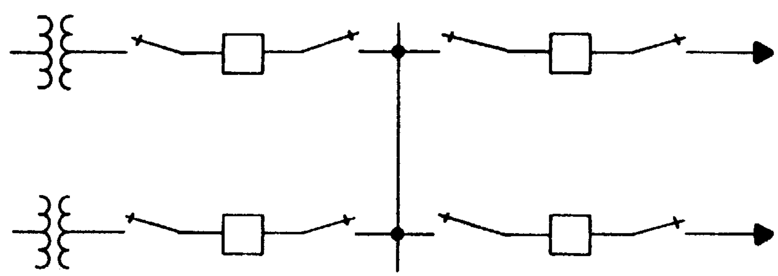
The typical bus configurations may be used for distribution, transmission or switching substations at voltages up to 230 kV. Details will vary depending on the type and voltage(s) of the substations. The physical size, type and arrangement of major equipment, such as power transformers, power circuit breakers and switches, may cause variance in the layouts to suit individual requirements. Portions of different layouts may be combined, as required, to achieve desired configurations.

It is important that the Engineer's plans remain as flexible as possible during substation layout to allow for unforeseen difficulties as his designs progress. He should coordinate his activities with the equipment manufacturers to ensure that each design detail reflects the actual equipment to be used.

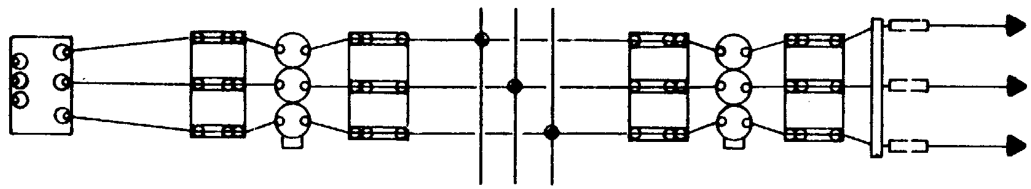
2. Single Bus

A single bus configuration consists of one main bus that is energized at all times and to which all circuits are connected. This arrangement is the simplest, but provides the least amount of system reliability. Bus faults or failure of circuit breakers to operate under fault conditions results in complete loss of the substation. The single bus configuration can be constructed by using either low or high profile type structures. Figure IV-10 illustrates the single bus arrangement with low profile structures and presents a neat, orderly plan. The high profile design, shown in Figure IV-11, accomplishes the same purpose and may not require as large a site for a given system voltage.

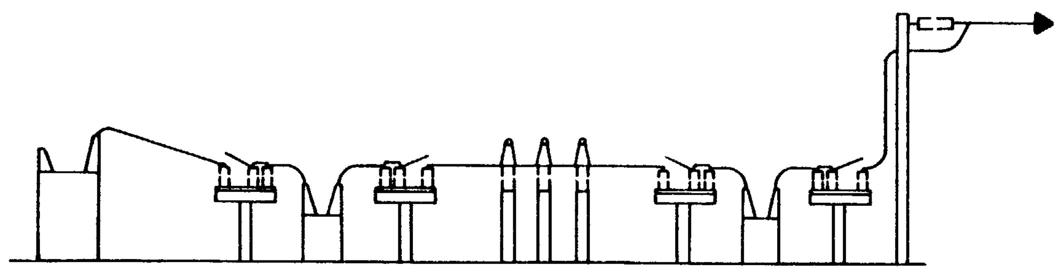
The single bus arrangement is not recommended without circuit breaker bypass facilities that permit circuit



TYPICAL ONE LINE DIAGRAM

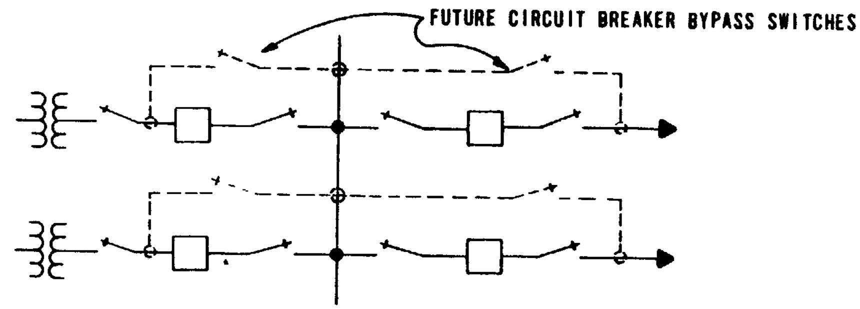


PLAN VIEW-TYPICAL BAY

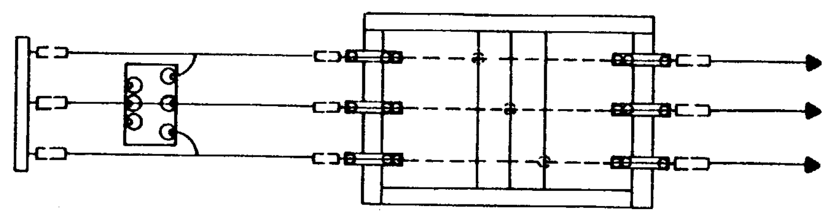


ELEVATION-TYPICAL BAY

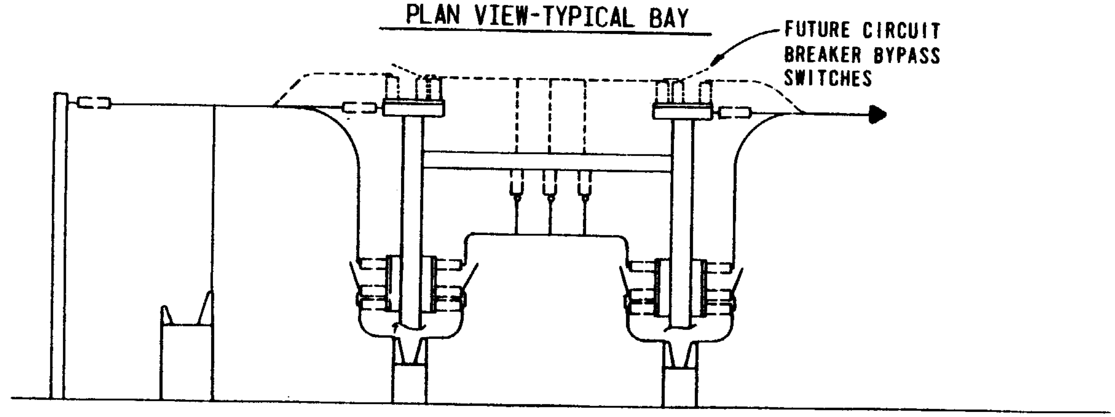
FIGURE IV-10 SINGLE BUS-LOW PROFILE



TYPICAL ONE LINE DIAGRAM



PLAN VIEW-TYPICAL BAY



ELEVATION-TYPICAL BAY

FIGURE IV-11 SINGLE BUS-HIGH PROFILE

breaker maintenance while maintaining circuit operation. The high profile configuration can easily be modified to provide this feature by installing group operated switches and the associated buswork and connections in the positions shown in Figure IV-11. This arrangement, however, results in loss of overcurrent protection for the circuit except by remote circuit breakers during the bypassing operations. A fault occurring on the line with the breaker bypassed would result in complete substation shutdown. The low profile arrangement does not allow for future addition of this type of bypassing equipment. Consequently, in both low profile and some high profile substations, the bypass facilities can be installed outside the substation. Switches can be provided that, when closed, parallel two lines to enable one circuit breaker to be removed from service. The other breaker then protects both circuits. If this bypassing method is used, the equipment associated with both circuits must be capable of carrying the total load of both circuits. If the load is greater than the equipment capability, the load should be reduced. This method of circuit breaker bypassing may be more desirable in high profile arrangements than that shown in Figure IV-11 for lines where frequent or lengthy equipment maintenance is expected.

The high profile configuration shown in Figure IV-11 is generally limited to distribution and subtransmission voltage levels. At transmission voltage levels, independent structures and strain bus interconnections are usually used.

Advantages

1. Lowest cost

2. Small land area required

3. Easily expandable

4. Simple in concept and operation

5. Relatively simple for the application of protective relaying

Disadvantages

1. High profile arrangement equipped with circuit breaker bypass facilities does not provide for circuit protection when bypass facilities are being used inside the substation

2. Lowest reliability

3. Failure of a circuit breaker or a bus fault causes loss of the entire substation

4. Maintenance switching can complicate and disable some of the protective relay scheme and overall relay correlation

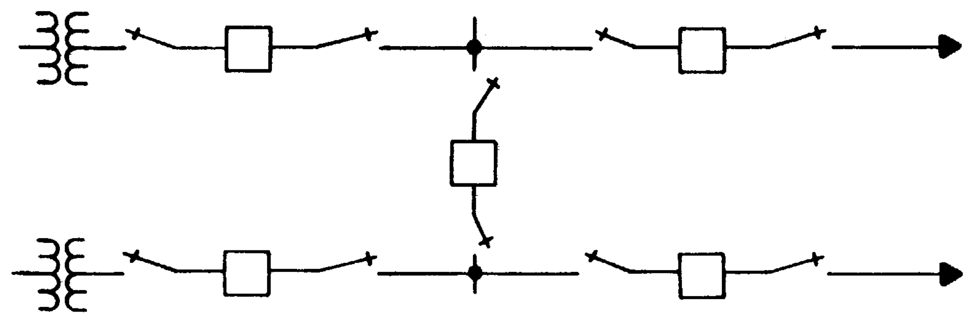
5. Maintenance at the upper elevations of high profile arrangements necessitates de-energization or protection of the lower equipment

3. Sectionalized Bus

An extension of the single bus configuration is the sectionalized bus arrangement shown in Figure IV-12. This arrangement is basically two or more single bus schemes, each tied together with bus sectionalizing breakers. The sectionalizing breakers may be operated normally open or closed, depending on system requirements. In this arrangement, a bus fault or breaker failure causes only the affected bus section to be removed from service and thus eliminates total substation shutdown. Usually, the fault can be isolated and nonfaulted portions of the system restored to service easier and faster because of the increased flexibility of the arrangement.

Physically, the equipment can be organized similar to that shown in Figures IV-10 and IV-11 for the single bus arrangement. The sectionalizing breakers and their associated isolation switches are located in line with the main bus. In the high profile configuration, it is usually desirable to provide a separate bay for the sectionalizing breakers and switches to facilitate maintenance and removal.

The arrangement of lines and transformers in a sectionalized bus arrangement is dependent upon system operating criteria. They should be so arranged to prevent outage of lines or other circuits dependent on each other. This



TYPICAL ONE LINE DIAGRAM

(SEE FIGURES IV-10 & IV-11
FOR TYPICAL ARRANGEMENTS)

FIGURE IV-12 SECTIONALIZED BUS

can be accomplished by positioning the interrelated circuits on different bus sections to eliminate concurrent shutdown. A thorough analysis of all possible operational contingencies identifying any undesirable conditions should precede the final determination of circuit grouping.

Bypassing arrangements for the sectionalized bus configuration can be provided as explained for the single bus scheme.

Advantages

1. Flexible operation

2. Higher reliability than single bus scheme

3. Bus sections can be isolated for maintenance

4. Only part of the substation is lost for a breaker failure or a bus fault

Disadvantages

1. Higher cost than single bus scheme

2. Additional circuit breakers required for sectionalizing

3. Sectionalizing may cause interruption of nonfaulted circuits

4. Main and Transfer Bus

A main and transfer bus configuration consists of two independent buses, one of which, the main bus, is normally energized. Under normal operating conditions, all incoming and outgoing circuits are fed from the main bus through their associated circuit breakers and switches. If it becomes necessary to remove a circuit breaker from service for maintenance or repairs, the integrity of circuit operation can be maintained through use of the bypass and bus tie equipment. The bypass switch for the circuit breaker to be isolated is closed, the bus tie breaker and its isolation switches are closed, and the bypassed breaker and its isolation switches are opened to remove the breaker from service. The circuit is then protected by the bus tie breaker.

Figure IV-13 illustrates a main and transfer bus configuration in a low profile arrangement. For comparison, Figure IV-14 shows the same switching scheme with high profile box-type structures. With the box-type structure arrangement, two circuit positions can be accommodated per equipment bay. However, with the low profile arrangement, each circuit requires its own bay and, as a result, somewhat more land area may be required. When the low profile configuration is used, equipment bays should be limited in width to a maximum of two bays before the bay to bay centerline spacing is increased to accommodate circuit breaker maintenance and removal. Without the additional space, these tasks can become very difficult.

The high profile, box-type structure arrangement shown in Figure IV-14 can accommodate multiple circuits in a relatively small area. The configuration is particularly suitable in environmentally shielded or otherwise isolated locations, where only a limited substation site is available. This arrangement is generally limited to distribution and subtransmission voltage levels. At transmission voltage levels, independent structures and strain bus interconnections can be used.

Advantages

1. Accommodates circuit breaker maintenance while maintaining service and line protection

2. Reasonable in cost

3. Fairly small land area required

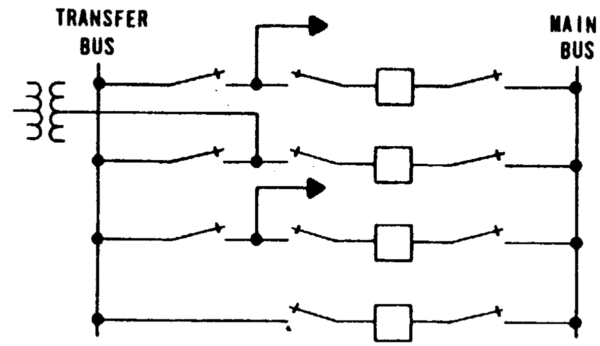
4. Easily expandable

Disadvantages

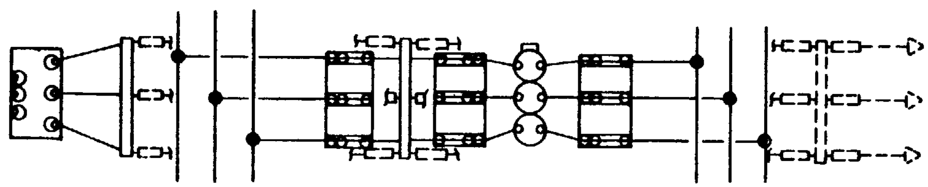
1. Additional circuit breaker required for bus tie

2. Since the bus tie breaker must be able to be substituted for any line breaker, its associated relaying may be somewhat complicated

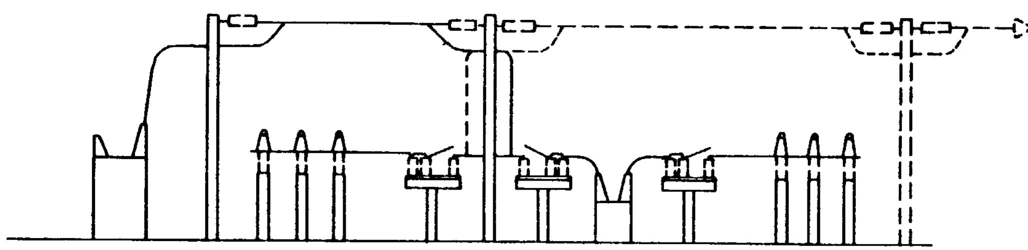
3. Failure of a circuit breaker or a bus fault causes loss of the entire substation



TYPICAL ONE LINE DIAGRAM



PLAN VIEW-TYPICAL BAY



ELEVATION TYPICAL BAY

FIGURE IV-13 MAIN AND TRANSFER BUS-LOW PROFILE

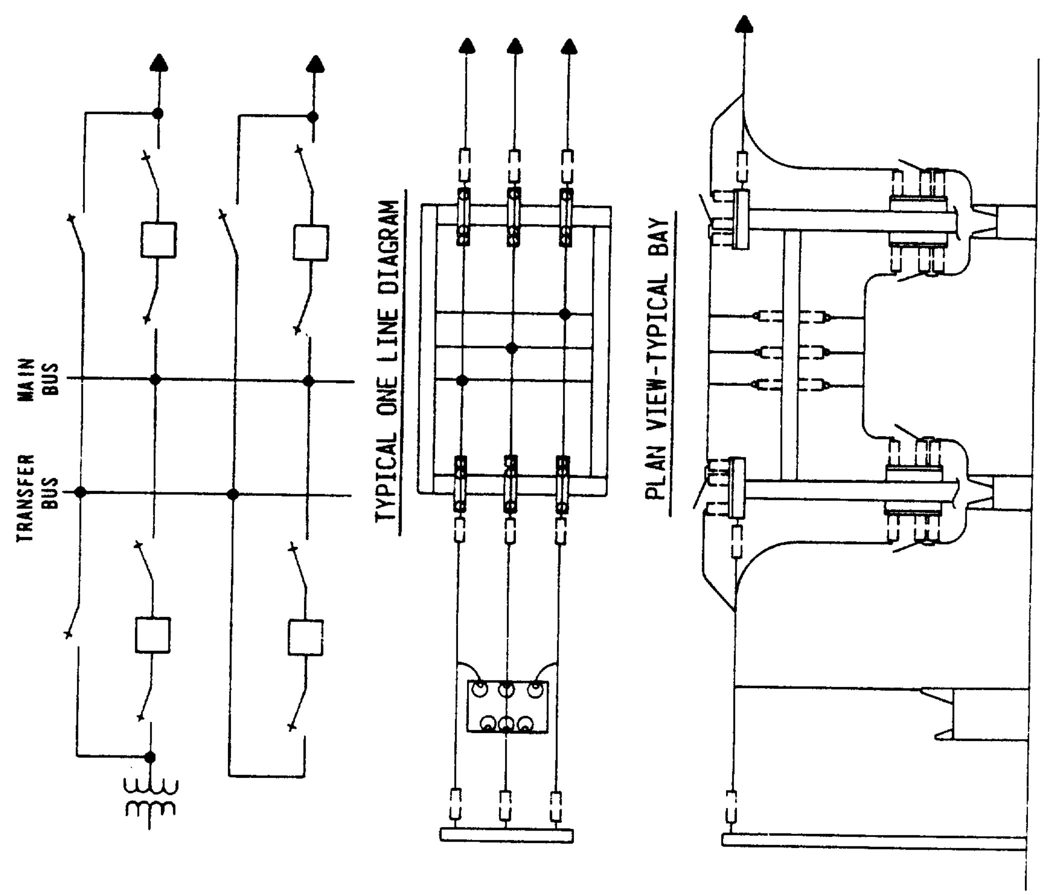


FIGURE IV-14 MAIN AND TRANSFER BUS-HIGH PROFILE

4. Somewhat complicated switching required to remove a circuit breaker from service for maintenance

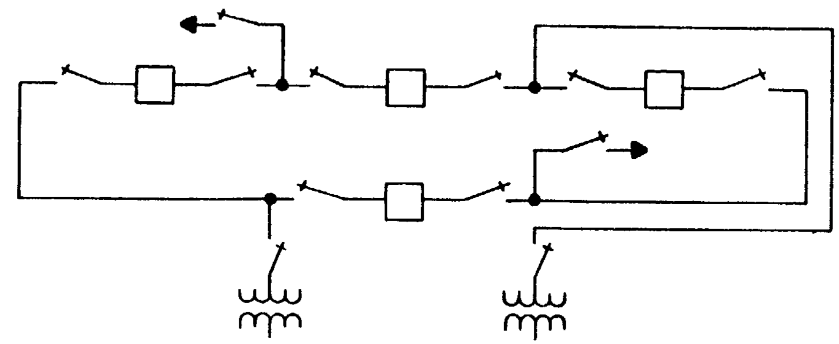
5. Ring Bus

A ring bus configuration is an extension of the sectionalized bus arrangement and is accomplished by interconnecting the two open ends of the buses through another sectionalizing breaker. This results in a closed loop or ring with each bus section separated by a circuit breaker. For maximum reliability and operational flexibility, each section should supply only one circuit.

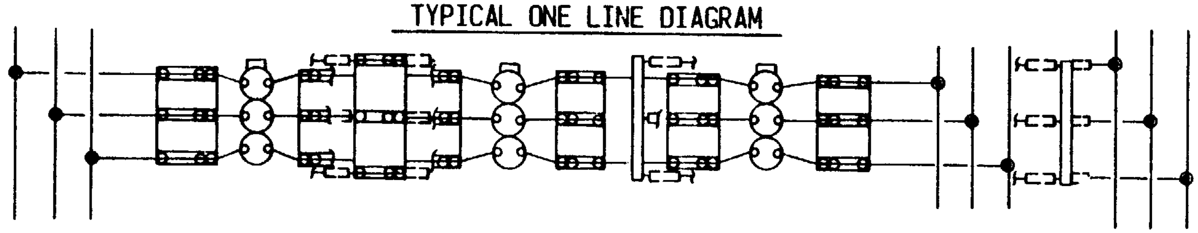
In this arrangement, as with the sectionalized bus configuration, only limited bus sections and circuits are removed from service because of line or bus faults or circuit breaker failure. For a line or bus fault, the two circuit breakers on the sides of the affected bus section open to isolate the fault. The remaining circuits operate without interruption. For a breaker failure, the two breakers on the sides of the affected breaker open to isolate the failed breaker and remove two bus sections from service.

The ring bus arrangement provides for circuit breaker maintenance, since any breaker can normally be removed from service without interruption of service to any circuits. As a result, separate circuit breaker bypass facilities are not required.

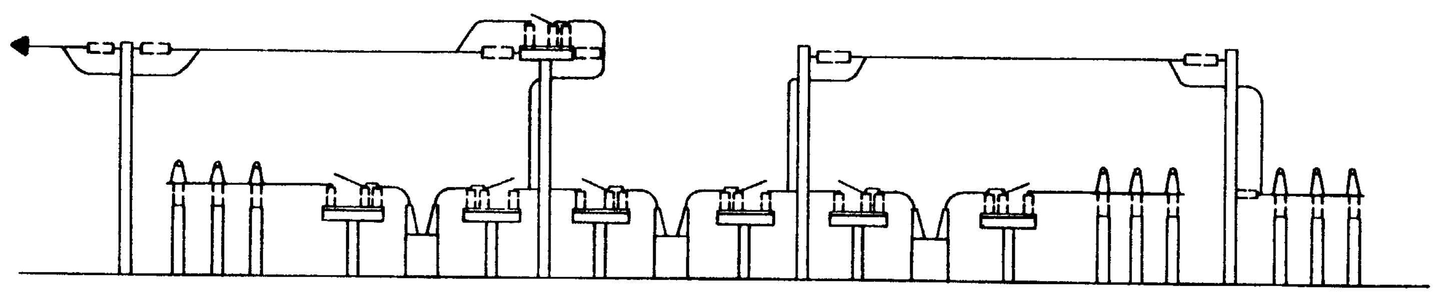
A number of equipment arrangements may be used to provide a ring bus configuration, depending on anticipated substation expansion and possible system modifications. Figure IV-15 illustrates a typical ring bus configuration. The arrangement shows four circuit positions, which is a practical maximum for a ring bus configuration. Rather than expanding the ring bus to accommodate additional circuits, other more flexible and reliable configurations, such as the breaker-and-a-half scheme, can be adopted. The ring bus arrangement shown in Figure IV-15 is readily adaptable in the future to a breaker-and-a-half configuration as shown in Figure IV-16. However, the relay and control panels must be carefully planned to be modified later for breaker-and-a-half operation.



TYPICAL ONE LINE DIAGRAM



TYPICAL PLAN VIEW



TYPICAL ELEVATION

FIGURE IV-15 RING BUS

Bay centerline spacing should be carefully planned to permit equipment maintenance and removal.

Advantages

1. Flexible operation

2. High reliability

3. Can isolate bus sections and circuit breakers for maintenance without disrupting circuit operation

4. Double feed to each circuit

5. No main buses

6. Expandable to breaker-and-a-half configuration

Disadvantages

1. Ring may be split by faults on two circuits or a fault during breaker maintenance to leave possibly undesirable circuit combinations (supply/load) on the remaining bus sections. Some consider this, however, to be a second contingency factor.

2. Each circuit must have its own potential source for relaying

3. Usually limited to a maximum of four circuit positions

6. Breaker-And-A-Half

The breaker-and-a-half configuration consists of two main buses, each normally energized. Electrically connected between the buses are three circuit breakers and, between each two breakers, a circuit as diagrammed in Figure IV-16. In this arrangement, three circuit breakers are used for two independent circuits; hence, each circuit shares the common center circuit breaker, so there are one-and-a-half circuit breakers per circuit.

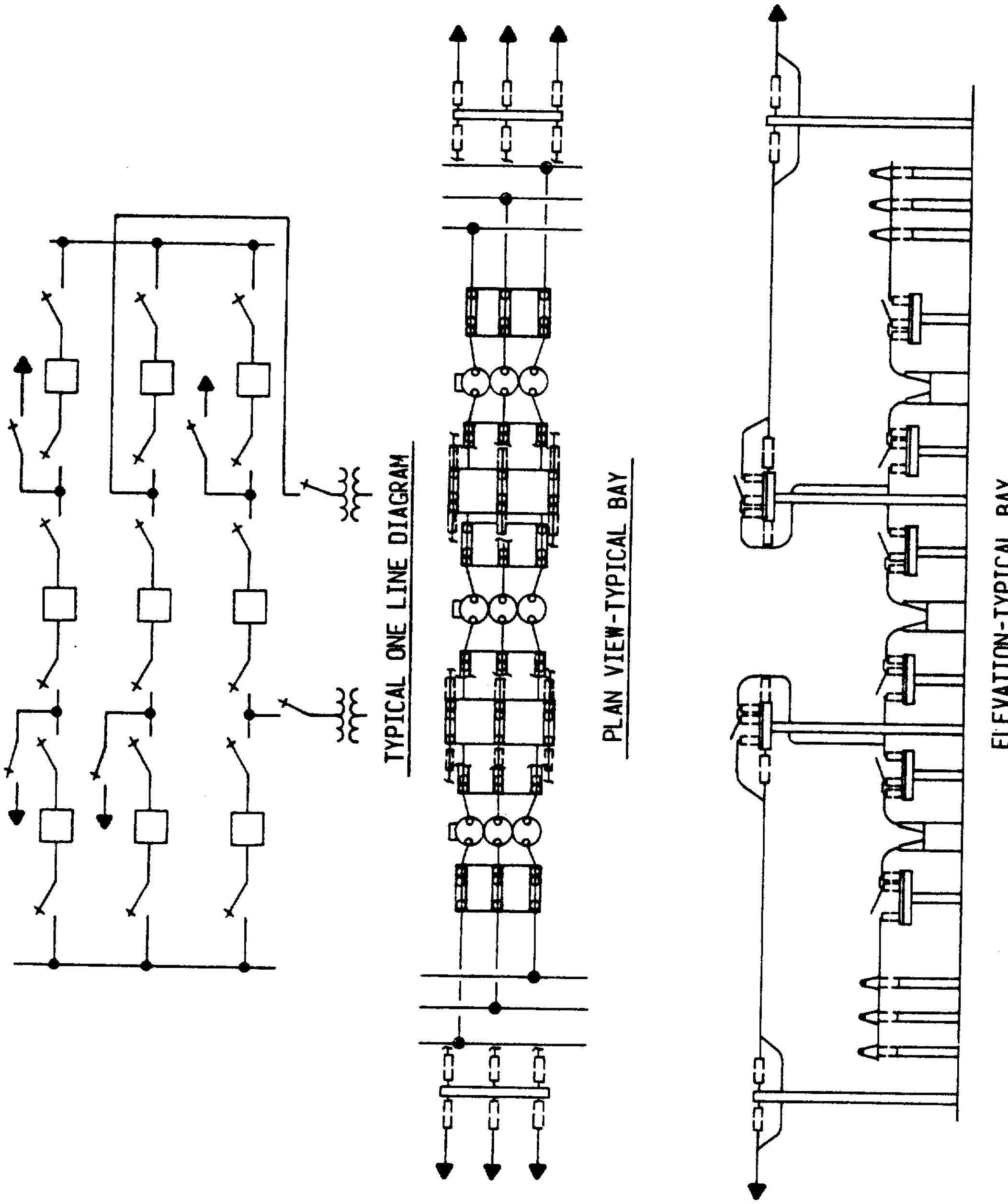


FIGURE IV-16 BREAKER-AND-A-HALF

The breaker-and-a-half configuration provides for circuit breaker maintenance, since any breaker can be removed from service without interrupting any circuits. Additionally, faults on either of the main buses cause no circuit interruptions. Failure of a circuit breaker results in the loss of two circuits if a common breaker fails and only one circuit if an outside breaker fails.

A typical bus configuration for a breaker-and-a-half arrangement is shown in Figure IV-16. This is the same basic equipment assemblage as described for the ring bus scheme.

Frequently, substations are initially constructed with a ring bus arrangement and ultimately expanded into a breaker-and-a-half configuration for the additional flexibility and reliability required with the additional circuits.

Bay centerline spacing should be carefully planned to permit equipment maintenance and removal.

Advantages

1. Flexible operation

2. High reliability

3. Can isolate either main bus for maintenance without disrupting service

4. Can isolate any circuit breaker for maintenance without disrupting service

5. Double feed to each circuit

6. Bus fault does not interrupt service to any circuits

7. All switching done with circuit breakers

Disadvantages

1. 1-1/2 breakers required per circuit

2. Involved relaying, since center breaker must respond to faults of either of its associated circuits

7. Double Breaker-Double Bus

The double breaker-double bus configuration consists of two main buses each normally energized. Electrically connected between the buses are two circuit breakers and, between the breakers, a circuit, as diagrammed in Figure IV-17. Two circuit breakers are required for each circuit.

In the double breaker-double bus configuration, any circuit breaker can be removed from service without interruption of any circuits. Faults on either of the main buses cause no circuit interruptions. Circuit breaker failure results in the loss of only one circuit.

A typical bus configuration for a double breaker-double bus arrangement is shown in Figure IV-17.

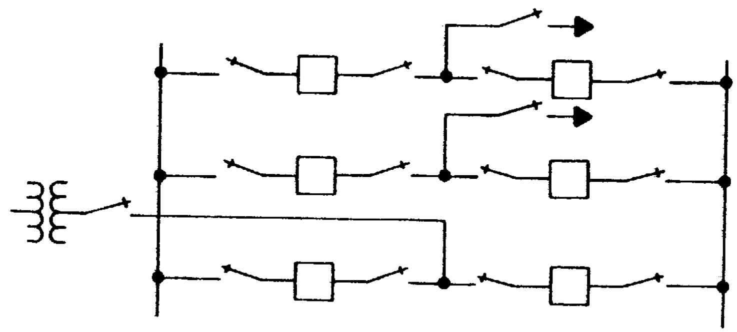
Use of the double breaker-double bus configuration is usually limited to large generating stations because of the high cost. The additional reliability afforded by this arrangement over the breaker-and-a-half scheme usually cannot be justified for conventional transmission or distribution substations.

Advantages

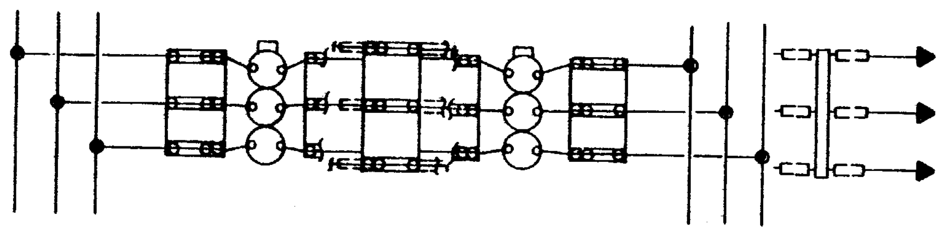
1. Flexible operation
2. Very high reliability
3. Can isolate either main bus for maintenance without disrupting service
4. Can isolate any circuit breaker for maintenance without disrupting service
5. Double feed to each circuit
6. Bus fault does not interrupt service to any circuits
7. Only one circuit lost for breaker failure
8. All switching done with circuit breakers

Disadvantages

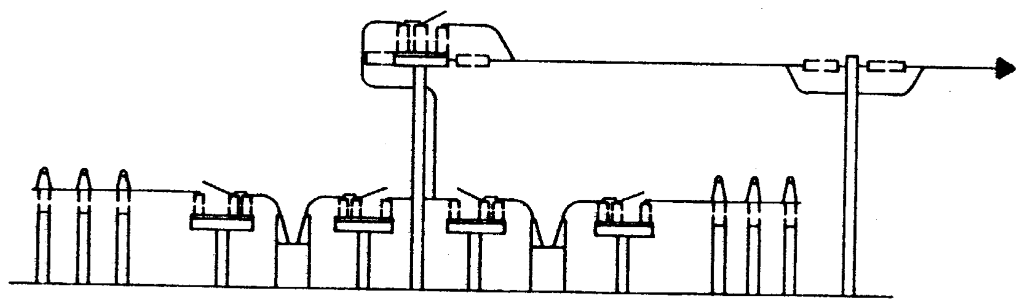
1. High cost
2. Two circuit breakers required for each circuit



TYPICAL ONE LINE DIAGRAM



PLAN VIEW-TYPICAL BAY



ELEVATION-TYPICAL BAY

FIGURE IV-17 DOUBLE BREAKER-DOUBLE BUS

8. Relative Switching Scheme Costs

The selection of a substation switching scheme is the result of the evaluation of many factors, including such intangibles as personal preference and judgment. Whatever arrangement is finally selected should meet all known or anticipated requirements, such as operating and maintenance criteria, future expansion, and reliability.

To assist in the evaluation, the following table provides a reasonable measure for the basis of economic comparison.

Switching Scheme	Approximate Relative Cost Comparison
Single Bus	100%
Sectionalized Bus	122%
Main and Transfer Bus	143%
Ring Bus	114%
Breaker-and-a-Half	158%
Double Breaker-Double Bus	214%

The comparison is based on four-circuit low profile arrangements with power circuit breakers in all circuits. Power transformer costs are not included. In schemes utilizing other protective devices or different circuit quantities, the relative costs may vary from those listed. It is recommended that detailed construction estimates be prepared for all schemes under consideration.

G. PROTECTION OF SUBSTATION INSULATION

1. General

Substation electrical equipment is subject to abnormal conditions as a result of direct lightning strokes, lightning surges, switching surges, and faults on the system. These abnormal conditions can cause overvoltages that may result in equipment flashover or insulation failure. To prevent equipment damage and/or system shutdown from overvoltages, protective devices are used to limit the overvoltages to reasonable levels. Application of these devices is usually a compromise between the costs of the devices and the degree of protection desired.

The protection provided for substations and substation equipment can be broken into two main parts - surge protection, employed to protect the equipment from damaging overvoltages caused by lightning surges, switching surges, and system faults; and direct stroke protection, employed to protect the equipment from direct lightning strokes.

2. Surge Protection

Surge arresters are used to protect equipment against overvoltages caused by incoming surges. The arresters function by discharging surge current to the ground system and then interrupt the current to prevent flow of normal power frequency follow current to ground. A detailed discussion concerning the application and selection of surge arresters can be found in Chapter V.

3. Direct Stroke Protection

a. Shielding

Since the effects of a direct lightning stroke to an unshielded substation can be devastating, it is recommended that some form of direct stroke protection be provided. Direct stroke protection normally consists of shielding the substation equipment by using lightning masts, overhead shield wires or a combination of these devices. The types and arrangements of protective schemes used are based on the size and configuration of the substation equipment.

b. Overhead Shield Wires

Overhead shield wires are often used to provide direct stroke protection. The shield wires can be supported by the circuit pull-off structures, if conveniently located, to extend over the substation. Since these shield wires are located above substation buses and equipment, breakage could result in outage of and/or damage to equipment. To minimize possible breakage, the overhead shield wire systems are constructed from high quality, high strength materials as listed in REA Bulletin 43-5, Item y. Shield wires should be limited to a maximum design tension of 8900 newtons (2000 pounds) per conductor under the appropriate loading conditions as defined in the National Electrical Safety Code. This tension is based only on wire strength and must be coordinated with support structure design. Lower tensions may be required for certain applications, depending on the capabilities of the support structures. Sag must be considered to ensure adequate clearance from energized equipment.

A complete overhead shield wire system should include protection for overhead circuits entering or leaving the substation. In areas not employing transmission line shielding, substation shield wire systems should be extended at least 805 meters (one-half mile) away from the substation to limit the exposure of the phase conductors to direct strokes near the substation. Strokes occurring on the circuits beyond the shielding will usually be attenuated enough by the time they reach the substation to be discharged successfully by the surge arresters without causing equipment damage. For adequate protection, the circuit shield wire systems should be directly connected to the substation shield wire system.

c. Shielding Masts

Shielding masts can be used for nearly all types of substations to provide protection against direct lightning strokes. They are particularly useful in large substations and those of low profile design. Shielding masts can be guyed or self-supporting steel poles or lattice type towers and are usually made of steel. Other materials, such as precast concrete or aluminum, can also be used.

In some instances, shielding masts can also be used to provide support for substation lighting equipment.

d. Zone of Protection

The zone of protection of a shielding system is the volume of space inside which equipment is considered adequately protected by the system. A shielding system allowing no more than 0.1 percent of the total predicted number of lightning strokes to terminate on the protected equipment is considered adequate for most situations. The shaded areas in Figure IV-18 illustrate the zones of protection afforded by single and double mast or shield wire systems. For a single mast, the zone of protection consists of a cone. For a single shield wire, the zone of protection is a wedge. When two or more masts or shield wires are used, the zones of protection of each overlap to provide complete coverage. The table shown in Figure IV-18 lists the ranges of angles that have been used for various shielding systems.

ANGLE	RANGE	RECOMMENDED
A	20° TO 60°	30°
B	40° TO 60°	45°

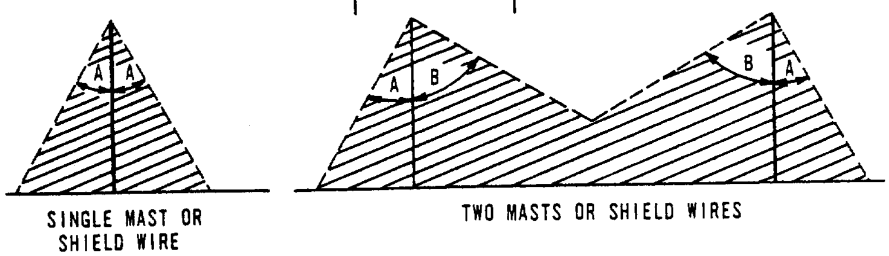


FIGURE IV-18 ZONES OF PROTECTION FOR MASTS AND SHIELD WIRES

e. Shielding System Grounding

A shielding system cannot effectively protect substation equipment unless adequately grounded. Multiple low impedance connections from the shielding system to the substation ground grid are essential. It is beneficial to use at least two separate connections to ensure continuity and reliability. Whenever nonconducting masts or supports are used, separate ground cables to establish a direct connection should be installed from the shield system to the substation ground system.

H. SUBSTATION INSULATORS

1. Outdoor Apparatus Insulators

a. Types

Outdoor apparatus insulators are used primarily to support rigid buswork and other electrical equipment operated above ground potential. Apparatus insulators are normally manufactured from electrical grade wet-process porcelain and are available in two major types: cap and pin type and post type. Other types are also available from some insulator manufacturers.

b. Cap and Pin Type Outdoor Apparatus Insulators

Cap and pin type apparatus insulators are the original insulator type used in substation construction.

Cap and pin insulators are usually manufactured with at least two shells of different diameter cemented together to achieve the required electrical characteristics. The spacing and configuration of the shells generally prevent flashover caused by dripping water. The wide shell spacing also permits natural cleaning of the exposed surfaces, to minimize the build-up of surface contamination.

The wide shells of the insulators are susceptible to damage from flashovers and other causes. Since the insulators rely on the large shell diameters to provide their electrical characteristics, breakage or other damage to the shells can greatly reduce the electrical characteristics and possibly cause permanent insulator failure.

Cap and pin insulators are available in two types - stacking and nonstacking. Single nonstacking insulators are normally used through nominal voltages of 46 kV (250 kV BIL). At nominal voltages of 69 kV (350 kV BIL) and above, stacking type insulators are used.

Cap and pin apparatus insulators are manufactured and tested in accordance with the following standards:

ANSI C29.1	Test Methods for Electrical Power Insulators

ANSI C29.8	Standard for Wet-Process Porcelain Insulators (Apparatus, Cap and Pin Type)
NEMA HV1	High Voltage Insulators

c. Post Type Outdoor Apparatus Insulators

Post type apparatus insulators are the type most often used today for new substation construction. The uniform profile and smaller diameter enhance the insulator appearance.

Post type apparatus insulators are generally manufactured from one piece of electrical grade wet-process porcelain formed with a number of vertical skirts to achieve the required electrical characteristics. End caps for mounting the insulators are cemented to the porcelain. Since the insulators are manufactured with a minimum number of joints, they are more rigid than the cap and pin type and, consequently, have reduced deflections.

The short skirts of post insulators make them less susceptible to damage from flashovers than the cap and pin type. Even if some of the skirts are damaged, insulation integrity is usually maintained, since the dry arcing distances are not greatly affected.

Post type insulators are available in two types - stacking and nonstacking. Single nonstacking insulators are normally used through nominal voltages of 69 kV (350 kV BIL). At nominal voltages of 115 kV (550 kV BIL) and above, stacking type insulators are used.

Since post type insulators are available in different colors, preferences should be made known in advance of purchasing.

Post type apparatus insulators are manufactured and tested in accordance with the following standards:

ANSI C29.1	Test Methods for Electrical Power Insulators
ANSI C29.9	Standard for Wet-Process Porcelain Insulators (Apparatus, Post Type)

d. BIL (Impulse Withstand) Ratings of Outdoor Apparatus Insulators*

Apparatus insulators are available with BIL (impulse withstand) ratings as listed in Table IV-1. Use of the BIL's for the nominal system voltages listed will normally ensure adequate coordination with protective devices and insulation systems of other equipment for most operating conditions. In areas of extremely high contamination, it may be desirable to increase the insulator BIL to levels higher than listed.

*For apparatus insulators, impulse withstand voltages are commonly referred to as BIL's.

TABLE 1V-1

Apparatus Insulator BIL (Impulse Withstand) Ratings for Nominal System Voltage

Nominal System Voltage kV	Apparatus Insulator BIL (Impulse Withstand) kV
14.4	110
23	150
34.5	200
46	250
69	350
115	550
138	650
161	750
230	900
230	1050

According to ANSI C37.30, "Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports," equipment that depends on air for its insulating medium will have a lower dielectric strength when operated at higher altitudes than when operating at lower altitudes. For altitudes above 1000 meters (3300 feet), the correction factors shown in Table IV-2 should be applied to reduce the insulator BIL's.

TABLE IV-2

Altitude Correction Factors

Altitude Meters (feet)	Correction Factors to Be Applied to BIL
1000 (3300)	1.00
1200 (4000)	0.98
1500 (5000)	0.95
1800 (6000)	0.92
2100 (7000)	0.89
2400 (8000)	0.86
2700 (9000)	0.83
3000 (10,000)	0.80
3600 (12,000)	0.75
4200 (14,000)	0.70
4800 (16,000)	0.65
5400 (18,000)	0.61
6000 (20,000)	0.56

e. Leakage Distance of Outdoor Apparatus Insulators

Cap and pin and post type apparatus insulators depend on the insulating material contours to achieve the required leakage distances. Breakage of a shell on a cap and pin type can greatly reduce the leakage distance and possibly cause insulator flashover. Skirt breakage on a post type usually will not cause insulator flashover, since a much smaller percentage of the total leakage distance is destroyed compared to the cap and pin type. Post type apparatus insulators generally have longer leakage distances than their counterparts, particularly at the lower BIL's.

In areas of high contamination it is usually desirable to utilize insulators with either longer than standard leakage distances or higher BIL's to prevent electrical breakdown from surface contamination. Application of insulators in unusual situations such as high contamination can sometimes best be accomplished by referring the problem to the insulator manufacturers for recommendations.

f. <u>Mechanical Strength of Outdoor Apparatus Insulators</u>

Most apparatus insulators are available in several mechanical strength ratings, based primarily on the cantilever strength of the insulators. The various ratings available can be found in ANSI and NEMA Standards and in manufacturers' literature.

The design and manufacture of post type apparatus insulators allow equal cantilever strength ratings in both upright and underhung mounting positions. Cap and pin apparatus insulators, however, have somewhat lower cantilever strengths in the underhung position than in the upright position. It is important to consider this difference when using cap and pin insulators.

For most applications, cantilever strength is the most important mechanical characteristic. However, depending on the actual insulator application, some of the other characteristics can become important and should be considered. These insulator characteristics include tensile strength, compressive strength, and torsional strength.

Typical characteristics of cap and pin type and post type apparatus insulators can be found in Tables IV-3 and IV-4, respectively.

TABLE IV-3

Typical Characteristics of Cap and Pin Type Apparatus Insulators

BIL (Impulse Withstand) kV	Technical Reference Number	Upright Cantilever Strength newtons (pounds)	Underhung Cantilever Strength newtons (pounds)	Bolt Circle centimeters (inches)	Height centimeters (inches)	Leakage Distance centimeters (inches)
110	4	8,896 (2000)	4,448 (1000)	7.62 (3)	25.4 (10)	30.5 (12)
110	44	17,792 (4000)	13,344 (3000)	12.7 (5)	25.4 (10)	35.6 (14)
150	7	8,896 (2000)	4,448 (1000)	7.62 (3)	30.5 (12)	50.8 (20)
150	46	17,792 (4000)	13,344 (3000)	12.7 (5)	30.5 (12)	45.7 (18)
200	10	8,896 (2000)	4,448 (1000)	7.62 (3)	38.1 (15)	71.1 (28)
200	49	17,792 (4000)	13,344 (3000)	12.7 (5)	38.1 (15)	71.1 (28)
250	13	8,896 (2000)	4,448 (1000)	7.62 (3)	45.7 (18)	91.4 (36)
250	53	17,792 (4000)	11,120 (2500)	12.7 (5)	50.8 (20)	102 (40)
350	16	6,672 (1500)	4,448 (1000)	7.62 (3)	73.7 (29)	132 (52)
350	56	13,344 (3000)	10,453 (2350)	12.7 (5)	73.7 (29) (1)	168 (66)
550	19	7,562 (1700)	6,539 (1470)	12.7 (5)	111 (43.5)(1)	252 (99)
550	173	12,899 (2900)	10,675 (2400)	12.7 (5)	111 (43.5)(1)	252 (99)
650	22	6,450 (1450)	5,560 (1250)	12.7 (5)	125 (49) (1)	269 (106)
650	180	10,453 (2350)	8,451 (1900)	12.7 (5)	125 (49) (1)	269 (106)
750	25	5,338 (1200)	4,759 (1070)	12.7 (5)	147 (58) (1)	335 (132)
750	123	8,896 (2000)	7,784 (1750)	12.7 (5)	147 (58) (1)	335 (132)
900	126	4,048 (910)	3,736 (840)	12.7 (5)	184 (72.5)(1)	419 (165)
900	27	6,450 (1450)	6,005 (1350)	12.7 (5)	184 (72.5)(1)	419 (165)
1050	128	3,336 (750)	3,114 (700)	12.7 (5)	221 (87) (1)	503 (198)
1050	28	5,204 (1170)	4,893 (1100)	12.7 (5)	221 (87) (1)	503 (198)

Notes:
(1) Does not include 8.89 centimeter (3.5 inch) high sub-base that is required for full BIL.
(2) The insulators listed are representative of those currently available. Additional ratings are available for some voltages. Refer to manufacturers' data for information.
(3) The characteristics listed are typical. Refer to manufacturers' data for actual ratings and additional characteristics.

TABLE IV-4

Typical Characteristics of Post Type Apparatus Insulators

BIL (Impulse Withstand) kV	Technical Reference Number	Upright Cantilever Strength newtons	(pounds)	Underhung Cantilever Strength newtons	(pounds)	Bolt Circle centimeters	(inches)	Height centimeters	(inches)	Leakage Distance centimeters	(inches)
110	205	8,896	(2000)	8,896	(2000)	7.62	(3)	25.4	(10)	39.4	(15.5)
110	225	17,792	(4000)	17,792	(4000)	12.7	(5)	30.5	(12)	39.4	(15.5)
150	208	8,896	(2000)	8,896	(2000)	7.62	(3)	35.6	(14)	61.0	(24)
150	227	17,792	(4000)	17,792	(4000)	12.7	(5)	38.1	(15)	61.0	(24)
200	210	8,896	(2000)	8,896	(2000)	7.62	(3)	45.7	(18)	94.0	(37)
200	231	17,792	(4000)	17,792	(4000)	12.7	(5)	50.8	(20)	94.0	(37)
250	214	8,896	(2000)	8,896	(2000)	7.62	(3)	55.9	(22)	109	(43)
250	267	17,792	(4000)	17,792	(4000)	12.7	(5)	61.0	(24)	109	(43)
350	216	6,672	(1500)	6,672	(1500)	7.62	(3)	76.2	(30)	183	(72)
350	278	13,344	(3000)	13,344	(3000)	12.7	(5)	76.2	(30)	183	(72)
550	286	7,562	(1700)	7,562	(1700)	12.7	(5)	114	(45)	251	(99)
550	287	12,899	(2900)	12,899	(2900)	12.7	(5)	114	(45)	251	(99)
650	288	6,450	(1450)	6,450	(1450)	12.7	(5)	137	(54)	295	(116)
650	289	10,898	(2450)	10,898	(2450)	12.7	(5)	137	(54)	295	(116)
750	291	5,338	(1200)	5,338	(1200)	12.7	(5)	157	(62)	335	(132)
750	295	8,896	(2000)	8,896	(2000)	12.7	(5)	157	(62)	335	(132)
900	304	4,048	(910)	4,048	(910)	12.7	(5)	203	(80)	419	(165)
900	308	6,450	(1450)	6,450	(1450)	12.7	(5)	203	(80)	419	(165)
1050	312	3,336	(750)	3,336	(750)	12.7	(5)	234	(92)	503	(198)
1050	316	5,204	(1170)	5,204	(1170)	12.7	(5)	234	(92)	503	(198)

Notes:
(1) The insulators listed are representative of those currently available. Additional ratings are available for some voltages. Refer to manufacturers' data for information.
(2) The characteristics listed are typical. Refer to manufacturers' data for actual ratings and additional characteristics.

g. Mounting Outdoor Apparatus Insulators

Most apparatus insulators are furnished with end caps with four mounting holes arranged in either 7.62 centimeter (3 inch), 12.7 centimeter (5 inch) or 17.8 centimeter (7 inch) bolt circles, depending on the insulator strength and voltage rating. The mounting holes are usually tapped for 1/2"-13 threads per inch, 5/8"-11 threads per inch, or 3/4"-10 threads per inch bolts, respectively. Adapters are available to go from one bolt circle size to another.

Upright or underhung mounting usually does not present major problems, provided the insulators are utilized within their mechanical and electrical capabilities. When the insulators are installed horizontally, the weight of the insulators, fittings, buses, and any other supported equipment must be considered to determine the permissible loads. Some manufacturers recommend reducing the allowable loads from the tabulated values for horizontally mounted insulators. Unusual applications can be referred to the manufacturers for recommendations.

2. Suspension Insulators

a. Types

Suspension insulators are used as insulation and support for strain buses in substations. Suspension insulators are available in several forms to suit individual requirements. Distribution dead-end type suspension insulators can be used at distribution voltages for substation strain buses. Distribution dead-end type suspension insulators normally have clevis type connections. Conventional suspension insulators are normally used for strain bus insulation at higher voltages and can be furnished with either clevis or ball and socket type connections. The conventional suspension insulators most commonly used, are 25.4 centimeters (10 inches) in diameter and 14.6 centimeters (5-3/4 inches) in length.

Suspension insulators acceptable for use on REA financed systems are listed in REA Bulletin 43-5, Item k.

b. Electrical Characteristics of Suspension Insulators

To achieve the necessary electrical characteristics, a number of suspension insulators are strung together in series. It is important to coordinate the insulation characteristics of suspension insulator strings with the insulation systems of other substation equipment and the characteristics of various insulation protective devices.

The quantity of suspension insulators chosen for a particular application should be large enough to prevent unnecessary flashovers. Overinsulation, however, can result in flashovers occurring from phase to phase rather than from phase to ground. Consequently, the quantity of insulators should be small enough that all flashovers occur to ground.

Table IV-5 lists the recommended minimum quantities of standard 14.6 x 25.4 centimeter (5-3/4 x 10 inch) suspension insulators for particular nominal system voltages and BIL's. Above 1000 meters (3300 feet), the correction factors listed in Table IV-2 should be applied to the BIL's and the insulator quantities correspondingly increased. In areas of high contamination, it may be necessary to increase the insulator quantities or consider the use of specially designed equipment.

TABLE IV-5

Minimum Quantity of Suspension Insulators

Nominal System Phase-to-Phase Voltage kV	BIL kV	Minimum Quantity of Suspension Insulators*
14.4	110	2
23	150	2
34.5	200	3
46	250	4
69	350	5
115	550	8
138	650	9
161	750	10
230	900	12
230	1050	14

* For standard 14.6 x 25.4 centimeter (5-3/4 x 10 inch) suspension insulators

c. Mechanical Strength of Suspension Insulators

Suspension insulators are tested and categorized with simultaneous mechanical-electrical strength ratings, as listed in REA Bulletin 43-5. These strength ratings are not the actual loads the insulators are designed to operate under, but represent ultimate strengths. The insulators also have proof test ratings specified in ANSI C29.2 as one half of the mechanical-electrical ratings. These ratings are the actual loads that the insulators have withstood during testing. The maximum suspension insulator loading should not exceed 40 percent of the mechanical-electrical strength ratings listed in REA Bulletin 43-5.

I. ELECTRICAL CLEARANCES

Table IV-6 lists the electrical clearances for outdoor substation construction based on ANSI C37.32, "Schedules of Preferred Ratings, Manufacturing Specifications, and Application Guide for High Voltage Air Switches, Bus Supports, and Switch Accessories," and NEMA SG6, "Power Switching Equipment." The values identified as minimums should be maintained or exceeded at all times. Phase-to-ground clearances and phase-to-phase clearances should be coordinated to ensure that possible flashovers occur from phase-to-ground rather than from phase-to-phase.

Table IV-7 lists the phase spacing of various types of outdoor air switches, based on ANSI C37.32 and NEMA SG6. The minimum metal-to-metal clearances should be maintained at all times with the switches in the open position, closed position, or anywhere between the open and closed positions.

When nonrigid conductors are used for outdoor overhead substation buses, the movement of the conductors caused by temperature changes and wind and ice loads must be considered. The usual practice is to increase the centerline-to-centerline bus spacing and the phase-to-ground clearances to compensate for these conditions. The minimum metal-to-metal, bus centerline-to-centerline, and minimum ground clearances listed in Table IV-6 should be increased at least 50 percent for nonrigid conductors. Checks should be made to ensure that the minimum metal-to-metal clearances listed in Tables IV-6 and IV-7 are maintained or exceeded at all times for all expected temperature and loading conditions.

In some locations, contamination from airborne particles necessitates increasing the minimum electrical clearances. Usually satisfactory operation can be obtained by using clearances one step above those normally used. In extremely contaminated locations, additional clearance may be required.

Since the dielectric strength of air insulated equipment decreases with increasing altitude, the clearances listed in Table IV-6 must be modified for use at altitudes above 1000 meters (3300 feet). To determine appropriate clearances for use above 1000 meters (3300 feet), first derate the standard BIL's by applying the factors listed in Table IV-2. Then choose the clearances from Table IV-6 corresponding to the derated BIL's selected. For example, at an altitude of 2400 meters (8000 feet), a maximum voltage of 121 kV is to be used. From Table IV-2, the standard BIL of 550 kV must be derated by applying a multiplying factor of 0.86. The following table shows the effects of derating for 2400 meters (8000 feet):

Standard BIL's kV	Derated BIL's kV
550	473
650	559
750	645

A 650 kV BIL must be selected for use at 2400 meters (8000 feet) to provide a BIL equivalent to 550 kV at altitudes of 1000 meters (3300 feet) and below. The clearances to be used are those associated with the 650 kV standard BIL, as listed in Tables IV-6 and IV-7.

TABLE IV-6

Outdoor Electrical Substation Clearances

Nominal Phase-to-Phase Voltage kV	Maximum Phase-to-Phase Voltage kV	BIL kV	Minimum Metal-to-Metal for Rigid Conductors meters(inches)	Centerline-to-Centerline Phase Spacing for Rigid Buses meters(inches)	Minimum to Grounded Parts for Rigid Conductors meters(inches)	Minimum Between Bare Overhead Conductors and Ground for Personnel Safety meters (feet) (3)	Minimum Between Bare Overhead Conductors and Roadways Inside Substation Enclosure meters (feet)
14.4	15.5	110	0.305 (12)	0.610 (24)	0.178 (7)	2.74 (9)	6.10 (20)
23	25.8	150	0.381 (15)	0.762 (30)	0.254 (10)	3.05 (10)	6.71 (22)
34.5	38	200	0.457 (18)	0.914 (36)	0.330 (13)	3.05 (10)	6.71 (22)
46	48.3	250	0.533 (21)	1.22 (48)	0.432 (17)	3.05 (10)	6.71 (22)
69	72.5	350	0.787 (31)	1.52 (60)	0.635 (25)	3.35 (11)	7.01 (23)
115	121	550	1.35 (53)	2.13 (84)	1.07 (42)	3.66 (12)	7.62 (25)
138	145	650	1.60 (63)	2.44 (96)	1.27 (50)	3.96 (13)	7.62 (25)
161	169	750	1.83 (72)	2.74 (108)	1.47 (58)	4.27 (14)	7.92 (26)
230	242	900	2.26 (89)	3.35 (132)	1.80 (71)	4.57 (15)	8.23 (27)
230	242	1050	2.67 (105)	3.96 (156)	2.11 (83)	4.88 (16)	8.53 (28)

Notes:
(1) Values taken from ANSI C37.32 and NEMA SG6.
(2) Values listed are for altitudes of 1000 meters (3300 feet) or less. For higher altitudes, the altitude correction factors listed in Table IV-2 should be applied.
(3) This is the minimum clearance from the top of structure, equipment, or apparatus foundations to energized conductors.
(4) In no cases should the clearance from the top of a foundation to the bottom of equipment bushings or insulators of energized equipment or apparatus be less than 2.44 meters (8 feet).

TABLE IV-7

Phase Spacing of Outdoor Air Switches

Nominal Phase-to Phase Voltage kV	Maximum Phase-to Phase Voltage kV	BIL kV	Minimum Metal-to-Metal for Air Switches meters (inches)	Centerline-to-Centerline Phase Spacing meters (inches)		
				Vertical Break Disconnect Switches	Side or Horizontal Break Disconnect Switches	All Horn Gap Switches
14.4	15.5	110	0.305 (12)	0.610 (24)	0.762 (30)	0.914 (36)
23	25.8	150	0.381 (15)	0.762 (30)	0.914 (36)	1.22 (48)
34.5	38	200	0.457 (18)	0.914 (36)	1.22 (48)	1.52 (60)
46	48.3	250	0.533 (21)	1.22 (48)	1.52 (60)	1.83 (72)
69	72.5	350	0.787 (31)	1.52 (60)	1.83 (72)	2.13 (84)
115	121	550	1.35 (53)	2.13 (84)	2.74 (108)	3.05 (120)
138	145	650	1.60 (63)	2.44 (96)	3.35 (132)	3.66 (144)
161	169	750	1.83 (72)	2.74 (108)	3.96 (156)	4.27 (168)
230	242	900	2.26 (89)	3.35 (132)	4.87 (192)	4.87 (192)
230	242	1050	2.67 (105)	3.96 (156)	5.50 (216)	5.50 (216)

Notes: (1) Values taken from ANSI C37.32 and NEMA SG6.
(2) Values listed are for altitudes of 1000 meters (3300 feet) or less. For higher altitudes, the altitude correction factors listed in Table IV-2 should be applied.

In addition to the electrical clearances previously described, it is necessary to provide adequate space for equipment maintenance. In arrangements where equipment such as power circuit breakers, reclosers, disconnect switches, power transformers, or other equipment must be maintained while portions of adjacent equipment remain energized, sufficient space should be provided around the equipment to prevent accidental contact by maintenance personnel.

In arrangements with buses or equipment crossing over other buses and equipment, adequate clearance must be maintained between the adjacent buses and equipment for all operational conditions. Power transformers and power circuit breakers should be positioned to permit removal of any bushing. Switches and other equipment with externally moving parts should be located to prevent infringement on the minimum clearances listed in Tables IV-6 and IV-7 during operation or when in any position. Conductor, equipment, or support structure movement during heavily loaded or deformed conditions must be considered.

The clearances listed in Tables IV-6 and IV-7 are adequate for most situations and exceed the requirements of the National Electrical Safety Code. The clearances listed in the NESC must be maintained or exceeded at all times.

J. BARE CONDUCTORS

1. Conductor Materials

Copper and aluminum are the two major conductor materials used for substation buses and equipment connections. Both materials can be fabricated into various types of flexible or rigid conductors. The trend in substation construction is toward use of mostly aluminum conductors. Copper conductors are used principally for expansion of similar systems in existing substations.

The conductivity of aluminum is from 50 to 60 percent that of copper, depending on the aluminum alloy. Consequently, larger aluminum conductors are required to carry the same currents as the copper conductors. The larger aluminum conductor diameters result in greater wind and ice loads, but tend to minimize corona, which is more of a problem at higher voltages.

For the same ampacity, copper conductors weigh approximately twice as much as aluminum conductors. The higher copper conductor weights can result in more sag as compared with aluminum conductors for equal spans. To reduce the sag, it is usually necessary to increase the number of supports for rigid conductors or, in the case of flexible conductors, increase the tensions.

2. Rigid Conductors

Rigid electrical conductors are available in a variety of shapes and sizes to suit individual requirements. Some of the more commonly used shapes include flat bars, structural shapes, and tubes. Specific physical and electrical properties and application data can be obtained from the conductor manufacturers.

a. Flat Bars

Flat bars can be utilized for outdoor substation buses and are particularly suitable since they can be easily bent and joined. For high current applications, a number of flat bars can be grouped together leaving a small space between the bars to facilitate heat dissipation. The ampacity of a group of flat bars is dependent upon whether the bars are arranged vertically or horizontally. The number of bars that can be grouped together is limited because of skin and proximity effects.

Because of their inherent lack of rigidity, supports for flat bar buses are usually closely spaced to minimize the effects of meteorological loads and short circuit forces.

Flat bars are usually limited to use at lower voltages because of corona.

b. Structural Shapes

The structural shape conductors that have been used in outdoor substation construction consist primarily of angle and channel types. The flat surfaces permit bolting directly to support insulators and provide convenient connection points. To increase ampacity, two angles or channels can be used. Special fittings are usually required for these configurations. The positioning and grouping of structural shapes have similar limitations to those of flat bars.

The rigidity of both angle and channel shapes is somewhat higher than for flat bars of the same ampacity. Consequently, support spacing can usually be increased.

c. Tubular Shapes

Square and round tubular shapes are considerably more rigid than either flat bars or structural shapes of the same ampacity and permit longer spans. The flat surfaces of square tubes provide convenient connection and support points. To facilitate heat dissipation, ventilation holes are sometimes provided in the square tubes. Round tubular conductors are the most popular shape used in outdoor substation construction. The round shape is very efficient structurally and electrically and minimizes corona at higher voltages. The special fittings required for connecting, terminating and supporting round tubular conductors are widely available.

d. Special Shapes

Special shapes combining the advantages of several of the standard shapes are also available. Integral web channel buses, uniform thickness angles, and other special configurations can be furnished.

e. Aluminum Alloys and Tempers

Aluminum conductors are available in a variety of alloys and tempers with different conductor conductivities and strengths. Round tubular conductors are usually specified as either 6061-T6 or 6063-T6 alloy. The 6063-T6 alloy has a conductivity approximately 23 percent higher and a minimum yield strength approximately 29 percent lower than the 6061-T6 alloy. Consequently, the 6063-T6 alloy can carry higher currents but may require shorter support intervals.

Both schedule 40 and 80 pipe are available in either alloy. The schedule 80 sizes have wall thicknesses approximately 40 percent thicker than the schedule 40 sizes resulting in lower deflections for equal span lengths.

Alloy 6106-T61 is frequently utilized for flat bars, structural shapes, and square tubes. Other alloys and tempers are available for special applications.

3. Flexible Conductors

Flexible electrical conductors can be used as substation buses and equipment taps. The conductors are normally cables fabricated by stranding a number of small conductors into one larger conductor. Stranding provides the required conductor flexibility while maintaining strength. The flexibility can be increased by reducing the diameter and increasing the quantity of individual conductors. Bare electrical cables for substation construction are usually concentric lay stranded with Class A or AA stranding per ASTM B231.

Most flexible conductors used in substation construction are all copper, all aluminum or aluminum with steel reinforcing (ACSR). The conductor type selected for a particular application is usually based on the span length, tension and tolerable sag, and cost. For long spans, large supporting structures will be required. The size and cost of these structures may depend on the conductor type and should be considered during the selection process.

Flexible conductors are available in many sizes. Size selection is based on ampacity, strength, weight, and diameter. Conductor diameter becomes increasingly important at higher voltages where corona can be a problem.

Data concerning the physical and electrical properties of the various wire types can be found in manufacturers' literature.

4. Conductor Ampacity

The ampacity of bare conductors is based on a number of factors, including the conductor material, proximity of the conductors, climatic conditions, conductor temperature rise, emissivity, and altitude.

Copper conductors can carry about 1.3 or more times as much current as aluminum conductors of the same size. However, based on weight, more than twice as much copper is required for the same ampacity.

The current distribution of closely spaced conductors is affected by their mutual inductance in accordance with the proximity effect. The additional losses attributed to this effect can usually be neglected if conductor spacing is 45.7 centimeters (18 inches) or greater.

Climatic conditions have a great effect on conductor ampacity. Ampacities are usually determined based on ambient temperatures of 40°C (104°F). For prolonged ambient temperatures above this value, ampacities are usually reduced. Wind tends to reduce the temperature of outdoor bare conductors. An assumed steady wind may be reasonable in many areas. The sun's radiation can cause the temperature of bare conductors to increase, which results in lower ampacities and should be considered in predominately sunny locations.

Conductor temperature rise is the temperature increase above ambient at which the conductor is operating. To prevent excessive surface oxidation and possible damage from annealing, the temperature rise is usually limited to 30°C (54°F) for a total maximum conductor temperature of 70°C (158°F) under normal operating conditions. The trend is toward higher operating temperatures. Temperature rises of 50°C (90°F) and higher have been used successfully. However, temperatures that could damage the conductors or connected equipment should be avoided.

The conductor surface emissivity has an effect or conductor ampacity. For aluminum conductors, emissivity is usually taken as 0.5 and for copper conductors 0.8. Both of these values are for heavily weathered conductor surfaces. The ampacity is usually higher for greater emissivity.

According to ANSI C37.30, "Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports," equipment that depends on air for its cooling medium will have a higher temperature rise when operated at higher altitudes than when operating at lower altitudes. For altitudes in excess of 1000 meters (3300 feet), the correction factors listed in Table VI-8 should be applied. Consider a conductor with an ampacity of 1000 amperes in a 40°C (104°F) ambient temperature with a 30°C (54°F) temperature rise at an altitude of 1000 meters (3300 feet). If this conductor is to be used at a higher altitude, the ampacity must be corrected. At 5400 meters (18,000 feet), this conductor will have an ampacity of 1000 x 0.910=910 amperes in an ambient temperature of 40°C (104°F) with a 30°F (54°F) temperature rise. The conductor may be operated at 1000 amperes at 5400 meters (18,000 feet), provided the ambient temperature does not exceed 40°C x 0.824=33°C (104°F x 0.824=85.7°F) and the temperature rise does not exceed 30°C (54°F).

TABLE IV-8

Altitude Correction Factors

Altitude meters (feet)	Correction Factors to be applied to Current Rating*	Correction Factors to be applied to Ambient Temperature*
1000 (3300)	1.00	1.00
1200 (4000)	0.995	0.992
1500 (5000)	0.990	0.980
1800 (6000)	0.985	0.968
2100 (7000)	0.980	0.956
2400 (8000)	0.970	0.944
2700 (9000)	0.965	0.932
3000 (10,000)	0.960	0.920
3600 (12,000)	0.950	0.896
4200 (14,000)	0.935	0.872
4800 (16,000)	0.925	0.848
5400 (18,000)	0.910	0.824
6000 (20,000)	0.900	0.800

*The correction factors for current rating and ambient temperature should not be applied at the same time.

5. Bus Connections

a. General

It is customary to purchase rigid bus conductors in lengths ranging from 3.05 meters (10 feet) to 12.2 meters (40 feet). Sections must be joined together for longer lengths. Taps are required from buses to electrical equipment. Bus conductors must be attached to support insulators. For greatest reliability and lowest cost, the fewer the connections the better.

The various substation bus connections can be made by using any of four main methods-bolting, clamping, compressing and welding-depending on the conductor type and material. Bolted connections are utilized in connecting two or more flat surfaces together. Clamp type connections generally involve the use of special fittings fabricated to permit conductors to be joined together or connected to other equipment. Compression connections are principally used for splicing or terminating flexible conductors. Welded connections are used primarily with rigid aluminum conductors. Weldment fittings are available that eliminate extensive conductor cutting and shaping prior to welding.

Whenever connectors are utilized for making electrical connections, they should be equivalent electrically and mechanically to the conductors themselves. Substation connectors are designed, manufactured, and tested in accordance with NEMA CC1, "Electric Power Connectors for Substations."

b. Bolted Connections

Bolted connections are the primary means used to make connections to equipment terminals. Bolted joints permit the disconnection of equipment for maintenance or replacement.

The most common bolted connection involves joining a conductor to an equipment terminal. A terminal lug is attached to the conductor by clamping, compressing, or welding, and the lug is bolted to the equipment terminal.

When a copper conductor is connected to a flat copper or electrical bronze equipment terminal, a copper or electrical bronze terminal lug is utilized. The lug is usually bolted to the equipment terminal with a minimum of two 1/2 inch-13 threads per inch high strength silicon bronze bolts normally torqued to 54.23 newton-meters (40 pound-feet). Silicon bronze flat washers are normally used under both the bolt heads and the nuts.

When an aluminum conductor is connected to a flat aluminum equipment terminal, an aluminum terminal lug is utilized. The lug is usually bolted to the equipment terminal with a minimum of two 1/2 inch-13 threads per inch anodized aluminum bolts normally torqued to 33.9 newton-meters (25 pound-feet). The bolts are usually aluminum alloy 2024-T4 and the nuts alloy 6061-T6. Flat washers of aluminum alloy 2024-T4 are normally used under both the bolt heads and the nuts. An anti-oxidation compound should also be considered for aluminum to aluminum connections.

When a copper conductor is connected to a flat aluminum equipment terminal, a copper or electrical bronze terminal lug is utilized. The lug is usually bolted to the equipment terminal with a minimum of two 1/2 inch-13 threads per inch bolts, normally of stainless steel or tin plated high strength silicon bronze. Flat washers of the same material as the other hardware are used under both the bolt heads and the nuts. Stainless steel spring washers are used between the flat washers and the nuts. Bolts are torqued to the spring washer manufacturer's recommendations.

When an aluminum conductor is connected to a flat copper or electrical bronze equipment terminal, an aluminum terminal lug is utilized. The lug is usually bolted to the equipment terminal with a minimum of two 1/2 inch-13 threads per inch bolts, normally of stainless steel or tin plated high strength silicon bronze. Flat washers of the same material as the other hardware are used under both the bolt heads and nuts. Stainless steel spring washers are used between the flat washers and the nuts. Bolts are torqued to the spring washer manufacturer's recommendations.

For aluminum-copper connections, the copper component should be installed below the aluminum component to prevent the copper salts from washing onto the aluminum. Additionally, the aluminum component should be massive, compared with the copper component. In many cases the copper connector should be tinned.

c. Clamp-Type Connections

A large variety of clamp-type electrical connectors are available for both flexible and rigid conductors of copper and aluminum. Most clamp-type connectors achieve their holding ability as a result of tightening a number of bolts. The quantities and sizes of bolts used should be as listed in NEMA CC1.

Copper or electrical bronze connectors should be utilized with copper conductors. All aluminum connectors should be used with aluminum conductors.

d. Compression Connections

Compression connections are primarily used in splicing or installing terminal lugs on flexible conductors. All-aluminum compression connectors should be used for aluminum conductors. Copper compression connectors should be used for copper conductors.

Installation of compression connectors in a vertical position with the lug down should be avoided to prevent the entrance of moisture and possible damage from freezing.

Compression connectors should always be installed in strict accordance with the manufacturer's instructions concerning the quantity and location of compressions. Connectors designed for a minimum of two circumferential compressions are recommended.

e. Welded Connections

Welded connections are used primarily with round tubular aluminum conductors. Use of the special fittings available simplifies the procedures to permit faster installation. Properly made welded connections have resistances that are not appreciably higher than the conductors themselves to eliminate conductor hot spots.

Welded aluminum connections are extensively used in the construction of large substations. Construction costs are usually slightly less with welded, compared to clamp type, connections. In smaller installations with fewer connections, it may not be economically feasible to weld connections.

K. RIGID BUS DESIGN

1. General Considerations

The design of a rigid bus system involves many factors, including:

a. Bus location in the substation and its proximity to other equipment. Ample clearance should be provided to permit equipment maintenance and removal. The bus should be situated to allow entrance of construction and maintenance equipment into the substation.

b. Future substation expansion. It is important to plan for future expansion by sizing and positioning buses to facilitate modifications.

c. Conductor selection. The bus conductors are selected based on ampacity, physical properties, and cost. Conductors must be selected so that they have sufficient size and capacity to withstand system faults and overcurrents without damage from overheating.

d. Short circuit conditions. During short circuits, large forces can be developed in the bus system. The rigid bus design includes consideration of these forces to prevent damage during short circuit conditions. The bus centerline to-centerline spacing and the short circuit current both have effects on these forces.

e. Wind and ice load. If not properly considered, wind and ice loads can cause extensive damage to bus conductors and insulators. The usual practice is to consider National Electrical Safety Code loadings as a minimum. Local conditions should be considered, since they may necessitate the use of more severe loading criteria.

f. Insulator strength. Since the number of different insulator ratings is limited, care should be exercised in the bus layout, so that a practical system is achieved. The strength of the insulators required is based on the total bus loading and particularly the short circuit forces.

g. Conductor sag. The sag of the bus conductors should be limited in the design. A flat horizontal system looks much neater than one with excessive sag. The conductor sag is influenced by the conductor weight and section modulus, the span length, and the vertical loading.

h. Aeolian vibration. Long conductor spans can be damaged by vibrations caused by winds. Excessive conductor sag can add to this problem. Span lengths whose natural frequency is near that set up by a wind that has a high recurrence should be avoided.

i. Conductor expansion. As the temperature of the conductors increases, longitudinal expansion occurs. If the bus system is not provided with means to absorb this expansion, insulators or other connected equipment can be damaged.

j. Location of conductor couplers. Long buses usually require the use of more than one section of conductor. Consequently, couplers must be utilized to join the sections together. These couplers must be properly located to prevent damage from bus loading and short circuit forces.

The bus system should be carefully planned by considering these aspects and other factors as they may develop. This section deals with the design of the conductor and support insulator systems. For data concerning supporting structures, refer to Chapter VII.

2. Procedure For Rigid Bus Design

The following procedure can be used in designing a rigid bus system:

a. Select the material and size of the bus conductors based on continuous current requirements. In higher voltage systems with longer bus spans, the structural capabilities of the conductors may be the factor that determines the conductor material and size. However, the conductors selected must be capable of carrying the required continuous current in any case.

b. Using Tables IV-6 and IV-7 from Section I of this chapter, determine the bus conductor centerline-to-centerline spacing.

c. Calculate the maximum short circuit forces the bus must withstand. These forces can be determined from the following equations:

$$F_{SC} = 13.9 \times 10^{-5} K_{SC} \frac{i^2}{D} \qquad (F_{SC} = 37.4 \times 10^{-7} K_{SC} \frac{i^2}{D}) \qquad \text{IV-1}$$

F_{SC}: maximum short-circuit force on center conductor for a three phase flat bus configuration of round or square tubular conductors with the conductors equally spaced, in newtons per meter (pounds per foot)

K_{SC}: short-circuit force reduction factor (0.5 to 1.0, 0.67 recommended)

i: rms value of three phase symmetrical short circuit current, in amperes

D: centerline-to-centerline spacing of bus conductors, in centimeters (inches)

d. Determine the total bus conductor loading. Table IV-9 lists values for wind and ice loading for the various loading districts defined in the National Electrical Safety Code. These values should be considered as minimum. Extreme wind should also be considered.

TABLE IV-9

NESC Conductor Wind and Ice Loads*

Load	Loading District Heavy	Medium	Light
Radial thickness of ice in centimeters (inches)	1.27(0.50)	0.635(0.25)	0
Horizontal wind pressure in pascals (pounds per square foot)	191.5(4.0)	191.5(4.0)	430.9(9.0)

*Conductor loading is usually based on these criteria. However, in locations where more severe conditions are frequent, the conductor loading should be based on actual local conditions.

The ice loading can be determined from the following equations:

$$W_I = 0.704\ (d_1^2 - d_2^2) \qquad (W_I = 0.311\ (d_1^2 - d_2^2)) \qquad \text{IV-2}$$

W_I: ice loading, in newtons per meter (pounds per foot)

d_1: outside diameter of conductor with ice, in centimeters (inches) (Determine ice thickness from Table IV-9.)

d_2: outside diameter of conductor without ice, in centimeters (inches)

The wind loading can be determined from the following equations:

$$F_W = 0.01\ P_W\ d_1 \qquad (F_W = 0.083\ P_W\ d_1) \qquad \text{IV-3}$$

F_W: wind loading, in newtons per meter (pounds per foot)

P_W: wind pressure, in pascals (pounds per foot^2) (from Table IV-9)

d_1: outside diameter of conductor with ice, in centimeters (inches)

The total bus conductor loading can be determined from the following equation:

$$F_T = [(F_{SC} + F_W)^2 + (W_C + W_I)^2]^{\frac{1}{2}} \qquad \text{IV-4}$$

F_T: total bus conductor loading, in newtons per meter (pounds per foot)

F_{SC}: maximum short circuit force, in newtons per meter (pounds per foot)

F_W: wind loading, in newtons per meter (pounds per foot)

W_C: conductor weight, in newtons per meter (pounds per foot) (If damping cables are used to control conductor vibration, add the cable weight to the conductor weight.)

W_I: ice loading, in newtons per meter (pounds per foot)

e. Calculate the maximum bus span or support spacing. This can be determined from the following equations:

$$L_M = K_{SM} \left[\frac{F_B S}{F_T} \right]^{\frac{1}{2}} \left(L_M = K_{SE} \left[\frac{F_B S}{F_T} \right]^{\frac{1}{2}} \right) \qquad \text{IV-5}$$

L_M: maximum bus support spacing, in meters (feet)

K_{SM}: multiplying factor from Table IV-10

K_{SE}: multiplying factor from Table IV-10

F_B: maximum desirable fiber stress of conductor, in kilopascals (pounds per inch^2)

For round tubular conductors of:

copper, $F_B = 1.38 \times 10^5$ kPa (20,000 lb/in^2)*

6061-T6 aluminum alloy,

$F_B = 1.93 \times 10^5$ kPa (28,000 lb/in^2)*

6063-T6 aluminum alloy,

$F_B = 1.38 \times 10^5$ kPa (20,000 lb/in^2)*

*Includes a safety factor of 1.25

S: section modulus of conductor, in $centimeters^3$ ($inches^3$)

F_T: total bus conductor loading, in newtons per meter (pounds per foot)

f. Calculate the maximum vertical conductor deflection from the following equations:

$$y = K_{DM} \frac{(W_C + W_I) L^4}{EI} \qquad \left(y = K_{DE} \frac{(W_C + W_I) L^4}{EI}\right) \qquad \text{IV-6}$$

y: maximum vertical conductor deflection, in centimeters (inches) (Limit this value to 1/200 of the span length. If the value calculated is greater than 1/200 of the span length, select a conductor with a larger diameter or reduce the span length. Recalculate as required.)

K_{DM}: multiplying factor from Table IV-10

K_{DE}: multiplying factor from Table IV-10

W_C: conductor weight, in newtons per meter (pounds per foot) (If damping cables are used to control conductor vibration, add the cable weight to the conductor weight.)

W_I: ice loading, in newtons per meter (pounds per foot)

L: bus support spacing, in meter (feet)

E: modulus of elasticity, in kilopascals (pounds per inch^2)

I: moment of inertia, in centimeters^4 (inches^4)

TABLE IV-10

Conductor Maximum Span and Deflection Multiplying Factors (K_{SM}, K_{SE}, K_{DM}, K_{DE})

Bus System	K_{SM}	(K_{SE})	K_{DM}	(K_{DE})
Conductor fixed both ends (single span)	0.110	(1.0)	2.6×10^4	(4.50)
Conductor fixed one end, simply supported other end (single span)	0.090	(0.82)	5.4×10^4	(9.34)
Conductor simply supported (single span)	0.090	(0.82)	1.3×10^5	(22.5)
Conductor simply supported (two equal spans)*	0.090	(0.82)	5.4×10^4	(9.34)
Conductor simply supported (three or more equal spans)*	0.096	(0.88)	6.9×10^4	(11.9)

*Maximum deflection occures in end spans

g. Determine the minimum required support insulator cantilever strength from the following equation:

$$W_S = 2.5\ (F_{SC} + F_W)\quad L_S\ * \qquad \text{IV-7}$$

W_S: minimum insulator cantilever strength, in newtons (pounds)

F_{SC}: maximum short circuit force, in newtons per meter (pounds per foot)

F_W: wind loading, in newtons per meter (pounds per foot)

L_S: one half of the sum of the lengths of the two adjacent conductor spans, in meters (feet)

*This equation includes an insulator safety factor of 2.5.

Select support insulators from Table IV-3 or IV-4 in Section H of this chapter or from manufacturers' data with cantilever strength ratings equal to or greater than W_S. If sufficiently high ratings are not available, it will be necessary to modify the bus design. This can be done by increasing the centerline-to-centerline conductor spacing to reduce the short circuit forces or by decreasing the bus span lengths.

h. Provide for thermal expansion of conductors. The amount of conductor thermal expansion can be calculated from the following equation:

$$\Delta l = \alpha\, l\, \Delta T \qquad \text{IV-8}$$

Δl: conductor expansion, in centimeters (inches) (final length minus initial length)

α: coefficient of linear thermal expansion

for aluminum, $\alpha = 2.3 \times 10^{-5}$ per degree Celsius (1.3×10^{-5} per degree Fahrenheit)

for copper, $\alpha = 1.7 \times 10^{-5}$ per degree Celsius (9.2×10^{-6} per degree Fahrenheit)

l: initial conductor length, in centimeters (inches) (at initial temperature)

ΔT: temperature variation, in degrees Celsius (Fahrenheit) (final temperature minus initial temperature)

Bus sections with both ends fixed without provisions for conductor expansion should be avoided. Connections to power circuit breakers, power transformers, voltage transformers, and other device bushings or terminals that could be damaged by conductor movement should be made either with flexible conductors or expansion type connectors.

Connections to switches utilizing apparatus insulators may require the use of expansion type terminal connectors to prevent damage from excessive conductor expansion. Use of expansion type terminals in this situation is dependent upon the bus configuration and location of other expansion points. It is recommended that expansion fittings used on long horizontal buses be limited to those permitting longitudinal expansion only.

It is usually desirable to limit the length of sections of continuous buses to 30.48 meters (100 feet) or less to limit the amount of conductor expansion in each section. This can be done by fixing certain points in the bus and permitting other points to move freely. An example of a typical bus system is diagrammed in Figure IV-19.

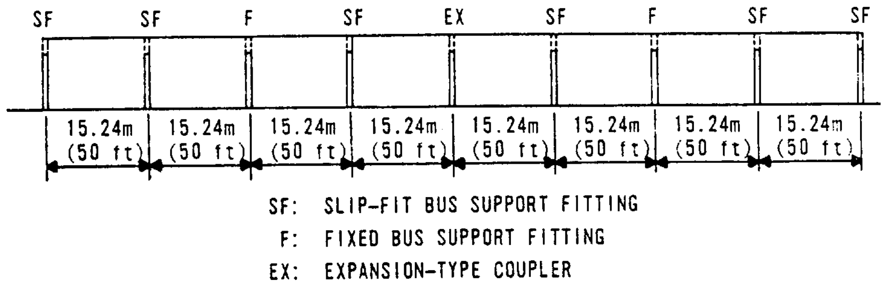


FIGURE IV-19 TYPICAL BUS SYSTEM ILLUSTRATING PROVISIONS FOR CONDUCTOR THERMAL EXPANSION

The system illustrated in Figure IV-19 can freely expand as necessary and is free of "captured spans" that permit no expansion. The locations of slip-fit and fixed bus supports and expansion-type couplers or bus supports divide the bus into four sections, each of which will expand approximately the same total amount. If it is desirable to connect the end sections of the bus to other equipment, flexible conductors or expansion-type connectors should be provided.

i. Locate conductor couplers. The couplers used on rigid buses should be as long as possible to provide maximum joint rigidity and strength. Clamp-type bolted couplers should have the quantity and size of clamping bolts as listed in NEMA CC1. Welded couplers for aluminum conductors should be of the internal type.

To prevent conductor damage from bending caused by its own weight and external loads, couplers should be carefully positioned. Welding and bolting can cause appreciable loss of conductor strength in the immediate coupler locations. Consequently, couplers should be positioned where the least amount of bending will occur. The ideal locations are points of zero bending moment along the conductor.

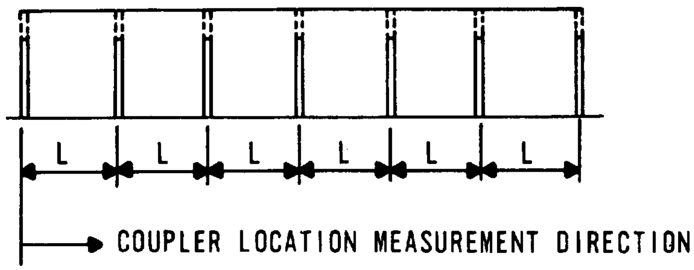
Table IV-11 lists the ideal locations for conductor couplers for continuous conductors.

TABLE IV-11

Ideal Locations for Couplers in Continuous Uniformly Loaded Rigid Conductors

Quantity of Conductor Spans	Ideal Coupler Locations Measured to the Right from the Left-most Support
1	*
2	0.750L, 1.250L
3	0.800L, 1.276L, 1.724L, 2.200L
4	0.786L, 1.266L, 1.806L, 2.194L, 2.734L, 3.214L
5	0.789L, 1.268L, 1.783L, 2.196L, 2.804L, 3.217L, 3.732L, 4.211L
6	0.788L, 1.268L, 1.790L, 2.196L, 2.785L, 3.215L, 3.804L, 4.210L 4.732L, 5.212L

*The zero moment locations for single span simply supported conductors are at the supports. Consequently, couplers are not recommended.



If couplers must be positioned in other than the ideal locations listed in Table IV-11, reduce the maximum allowable fiber stress used in Section 2(e) of this chapter by as much as 50 percent, dependent upon the degree of variation from the ideal location and recalculate the maximum span length. If the span length being considered exceeds this maximum, reduce it as necessary. Conductor couplers can now be positioned wherever convenient.

j. Consider aeolian conductor virbation. Aeolian conductor vibration is primarily the result of steady low velocity transverse winds striking the conductor and causing it to vibrate. When the frequency of the driving force (wind) is approximately equal to the natural frequency of the bus span, resonance occurs. The resulting vibrations can cause insulator damage.

Vibrations will occur in almost all bus spans independently of the conductor material, diameter, or length. In short spans, the vibrations are usually of small enough magnitude to be neglected. However, in spans longer than about 6.1 meters (20 feet), methods for vibration damping should be considered.

Two primary methods have been used to dampen aeolian vibrations. The first and most widely used method consists of installing scrap cables in the horizontal buses. When this method is used, it is necessary that the cables be loose in the bus tubing to permit vertical movement. If new cables are used, they should be straightened prior to installation to prevent the cables from jamming against the tubing sides. Additionally, end caps, preferably of the driven type, should be installed on the ends of the buses containing the damping cables to prevent horizontal cable movement out of the tubing. To be effective, damping cables should be installed for the entire bus length for buses where excessive vibration is suspected.

The second method used to dampen aeolian vibrations consists of installing internal or external prefabricated bus dampers on the bus conductors. Usually, one damper is installed in each bus span to control the vibrations. Location and installation should be in accordance with the manufacturer's instructions.

3. Bus Design Example

Design a three phase rigid bus with the following characteristics:

Total bus length: 45.72 meters (150 feet), assuming four equal spans of 11.43 meters (37.5 feet)

Voltage: 161 kV

BIL: 750 kV

Insulator type: post

Continuous current rating: 1800 amperes

Short-circuit current: 24,000 rms symmetrical amperes

Altitude: 304.8 meters (1000 feet)

NESC loading: heavy

Disconnect switch connected to one end of bus

External prefabricated dampers will be used to control conductor vibration

Following the procedure of Section K of this chapter:

a. Select the material and size of the bus conductors. Based on the continuous current requirements, 7.6 cm (3 in) SPS, schedule 40 6063-T6 aluminum alloy (1890 amperes) is selected with the following properties:

W_C (weight) = 38.2 N/m (2.62 lb/ft)*

d_2 (outside diameter) = 8.89 centimeters (3.50 inches)

I (moment of inertia) = 125.6 cm^4 (3.017 in^4)

E (modulus of elasticity) = 6.9 x 10^7 kPa (10 x 10^6 lb/in^2)

S (section modulus) = 28.2 cm^3 (1.72 in^3)

F_B (maximum allowable fiber stress) = 1.38 x 10^5 kPa (20,000 lb/in^2)

*If damping cables are to be used to control conductor vibration, the cable weight must be added to the conductor weight. In this example, external prefabricated dampers will be used for vibration control.

b. Determine the bus conductor centerline-to-centerline spacing from Table IV-6.

D (bus centerline-to-centerline spacing) = 274 cm (108 in)

c. Calculate the maximum short circuit force.

$$F_{SC} = 13.9 \times 10^{-5} K_{SC} \frac{i^2}{D} \qquad \left(F_{SC} = 37.4 \times 10^{-7} K_{SC} \frac{i^2}{D}\right)$$

$$F_{SC} = (13.9 \times 10^{-5})(0.67) \frac{(24{,}000)^2}{(274)} \qquad \left(F_{SC} = (37.4 \times 10^{-7})(0.67) \frac{(24{,}000)^2}{(108)}\right)$$

$$F_{SC} = 195.8 \text{ N/m} \qquad (F_{SC} = 13.4 \text{ lb/ft})$$

d. Determine the total bus conductor loading. From Table IV-9, Radial thickness of ice: 1.27 cm (0.50 in)

Horizontal wind pressure: 191.5 Pa (4.0 lb/ft^2)

$$W_I = 0.704\ (d_1^{\ 2} - d_2^{\ 2}) \qquad (W_I = 0.311\ (d_1^{\ 2} - d_2^{\ 2}))$$

$$W_I = (0.704)\ [(11.43)^2 - (8.89)^2] \qquad (W_I = 0.311\ [(4.50)^2 - (3.50)^2])$$

$$W_I = 36.3 \text{ N/m} \qquad (W_I = 2.49 \text{ lb/ft})$$

$$F_W = 0.01\ P_W d_1 \qquad (F_W = 0.083\ P_W d_1)$$

$$F_W = (0.01)(191.5)(11.43) \qquad (F_W = (0.083)(4.0)(4.50)$$

$$F_W = 21.9 \text{ N/m} \qquad (F_W = 1.49 \text{ lb/ft})$$

$$F_T = [(F_{SC} + F_W)^2 + (W_C + W_I)^2]^{1/2} \qquad (F_T = [(F_{SC} + F_W)^2 + (W_C + W_I)^2]^{1/2})$$

$$F_T = [(195.8 + 21.9)^2 + (38.2 + 36.3)^2]^{1/2} \qquad (F_T = [(13.3 + 1.49)^2 + (2.62 + 2.49)^2]^{1/2})$$

$$F_T = 230.1 \text{ N/m} \qquad (F_T = 15.6 \text{ lb/ft})$$

e. Calculate the maximum bus support spacing.

$$L_M = K_{SM} \left[\frac{F_B S}{F_T} \right]^{\frac{1}{2}} \qquad \left(L_M = K_{SE} \left[\frac{F_B S}{F_T} \right]^{\frac{1}{2}}\right)$$

Four equal spans of 11.43 meters (37.5 feet) were assumed. From Table IV-10, $K_{SM} = 0.096$ ($K_{SE} = 0.88$) for three or more equal spans.

$$L_M = (0.096) \left[\frac{(1.38 \times 10^5)(28.2)}{(230.1)} \right]^{\frac{1}{2}} \qquad \left(L_M = (0.88) \left[\frac{(20,000)(1.72)}{(15.6)} \right]^{\frac{1}{2}}\right)$$

$$L_M = 12.48 \text{ m} \qquad (L_M = 41.3 \text{ ft})$$

The assumed spacing of 11.43 meters (37.5 ft) is structurally permissible for the conductors.

f. Calculate the maximum vertical conductor deflection.

$$y = K_{DM} \frac{(W_C + W_I)\ L^4}{EI} \qquad \left(y = K_{DE} \frac{(W_C + W_I)\ L^4}{EI}\right)$$

Four equal spans of 11.43 meters (37.5 feet) were assumed. From Table IV-10, $K_{DM} = 6.9 \times 10^4$ ($K_{DE} = 11.9$) for three or more equal spans.

$$y = (6.9 \times 10^4) \cdot \frac{(38.2 + 36.3)(11.43)^4}{(6.9 \times 10^7)(125.6)} \qquad \left(y = (11.9) \cdot \frac{(2.62 + 2.49)(37.5)^4}{(10 \times 10^6)\ (3.017)}\right)$$

$$y = 10.1 \text{ cm} \qquad (y = 3.99 \text{ in})$$

Maximum permissible deflection is $\frac{1}{200}$ of the span length.

$$y_{max} = \frac{(11.43)(100)}{200} \qquad \left(y_{max} = \frac{(37.5)(12)}{200}\right)$$

$$y_{max} = 5.72 \text{ cm} \qquad (y_{max} = 2.25 \text{ in})$$

Since the calculated deflection is greater than the maximum permissible deflection, the design must be modified. The span length will be reduced to five equal spans of 9.14 meters (30 feet) each. The maximum vertical deflection is then recalculated.

$$y = (6.9 \times 10^4) \cdot \frac{(38.2 + 36.3)(9.14)^4}{(6.9 \times 10^7)(125.6)} \qquad \left(y = (11.9) \cdot \frac{(2.62 + 2.49)(30)^4}{(10 \times 10^6)(3.017)}\right)$$

$$y = 4.14 \text{ cm} \qquad (y = 1.63 \text{ in})$$

Maximum permissible deflection is:

$$y_{max} = \frac{(9.14)(100)}{200} \qquad \left(y_{max} = \frac{(30)(12)}{200}\right)$$

$$y_{max} = 4.57 \text{ cm} \qquad (y_{max} = 1.80 \text{ in})$$

Since the calculated value with 9.14 meter (30 foot) support spacing is less than the maximum permissible deflection, this support spacing is adequate.

g. Determine the minimum required support insulator cantilever strength.

$$W_S = 2.5\ (F_{SC} + F_W)\ L_S \qquad (W_S = 2.5\ (F_{SC} + F_W)\ L_S)$$

$W_S = (2.5)(195.8 + 21.9) \cdot \left(\frac{9.14}{2} + \frac{9.14}{2} \right)$ $\quad$ $(W_S = (2.5)(13.3 + 1.49) \cdot \left(\frac{30}{2} + \frac{30}{2} \right))$

$W_S = 4974$ N $\quad$ $(W_S = 1109$ lb)

From Table IV-4, select Technical Reference Number 291 for 5338 newton (1200 pound) cantilever strength post type insulators.

h. Provide for conductor expansion. Assuming a total conductor temperature variation of 50°C (90°F), the total conductor expansion is:

$\Delta 1 = \alpha 1 \Delta T$ $\quad$ $(\Delta 1 = \alpha 1 \Delta T)$

$\Delta 1 = (2.3 \times 10^{-5})(45.72) \cdot (100)(50)$ $\quad$ $(\Delta 1 = (1.3 \times 10^{-5})(150) \cdot (12)(90))$

$\Delta 1 = 5.26$ cm $\quad$ $(\Delta 1 = 2.11$ in)

Some means must be provided to account for this change. Figure IV-20 illustrates one method that can be used that permits free expansion in all spans:

SF: Slip-fit bus support

F: Fixed bus support

EX: Expansion terminal

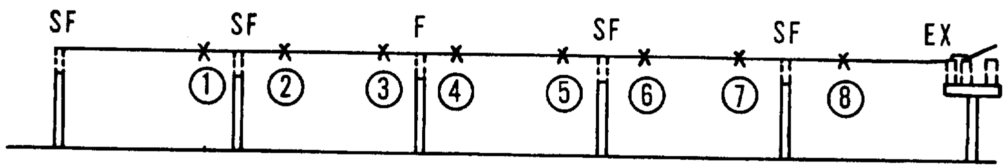


FIGURE IV-20 BUS CONFIGURATION FOR EXAMPLE

i. Locate conductor couplers. From Table IV-11, the ideal coupler locations for the five span bus of 9.14 meter (30 foot) spans measured to the right from the left-most support are as follows:

1	7.2 m	(23.7 ft)
2	11.6 m	(38.0 ft)
3	16.3 m	(53.5 ft)
4	20.1 m	(65.9 ft)
5	25.6 m	(84.1 ft)
6	29.4 m	(96.5 ft)
7	34.1 m	(112.0 ft)
8	38.5 m	(126.3 ft)

These locations are illustrated in Figure IV-20. Assuming that the bus conductor is available in 12.19 meter (40 foot) lengths, the couplers should be positioned at points 2, 4, 6 and 8. The conductor lengths are cut as required to position the couplers at these approximate locations.

j. Consider aeolian vibration. Since the spans are fairly long, damaging vibrations may occur. Consequently, a means for controlling the vibrations should be provided. Prefabricated dampers can be attached to the buses or scrap cables can be installed in the buses. If cables are used, the cable weight must be added to the conductor weight for the bus calculations.

L. STRAIN BUS DESIGN

1. General Considerations

Strain bus design involves many factors, including:

a. Bus location in the substation and its proximity to other equipment. The flexible conductors used for strain bus construction permit significant conductor movement. Consequently the conductors must be carefully positioned to prevent contact with other equipment and infringement upon minimum electrical clearances under all loading and climatic conditions. Equipment maintenance and removal should also be considered in locating buses and support structures.

b. Future substation expansion. Strain buses usually require large supporting structures. These structures can limit future expansion if not properly positioned.

c. Conductor selection. The conductor is selected based on ampacity, physical properties and cost. Conductors must be selected so that they have sufficient size and capacity to withstand system faults and overcurrents without damage from overheating.

d. Wind and ice load. Wind and ice can increase conductor sags and tensions appreciably. The usual practice is to consider National Electrical Safety Code loadings as a minimum. Local conditions should be considered, since they may necessitate the use of more severe loading criteria.

e. Insulator strength. The suspension insulators are selected based on the anticipated maximum loading conditions. The maximum loading should not exceed 40 percent of the mechanical-electrical strength ratings listed in REA Bulletin 43-5.

f. Span length. The span length influences the conductor sag. As the span length increases, the sag increases if the same tension is maintained. To limit the sag, the tensions can be increased. Springs can also be used to limit the tension and sag.

g. Sag and tension. Strain buses are usually positioned above other substation equipment. Conductor breakage could result in equipment damage or outage. To prevent breakage and to minimize support structure size, the conductors are usually installed at tensions of approximately 13,350 newtons (3000 pounds) or less. Sag may increase because of the deflection of support structures.

h. Temperature variations. Temperature variations cause changes in the conductor lengths. As the conductor temperature increases, the sag increases and the tension decreases.

i. Tap loads. Taps from the conductors to other buses or equipment should be limited in tension to prevent damage to equipment. The taps are usually installed as slack connections.

2. Procedure For Strain Bus Design

The following procedure can bé used to design a strain bus system:

a. Select the material and size of the bus conductors, based on continuous current requirements.

b. Using Tables IV-6 and IV-7 from Section I of this chapter, determine the bus conductor centerline-to-centerline spacing. As explained in Section I, the minimum metal-to-metal, bus centerline-to-centerline, and minimum ground clearances listed in Table IV-6 should be increased at least 50 percent for nonrigid conductors.

c. Select the quantity of suspension insulators from Table IV-5 in Section H of this chapter.

d. Determine the total bus conductor loading. Table IV-12 lists values for wind and ice loading for the various loading districts defined in the National Electrical Safety Code. These values should be considered as minimum.

TABLE IV-12

NESC Conductor Loading Criteria*

Load	Loading District Heavy	Loading District Medium	Loading District Light
Radial thickness of ice in centimeters (inches)	1.27(0.50)	0.635(0.25)	0
Horizontal wind pressure in pascals (pounds per square foot)	191.5(4.0)	191.5(4.0)	430.9(9.0)
Temperature in degrees Celsius (degrees Farenheit)	-18(0)	-9.4(+15)	-1.1(+30)
Constant (k) to be added to the resultant	4.38(0.30)	4.38(0.20)	0.73(0.05)

*Conductor loading is usually based on these criteria. However, in locations where more severe conditions frequently occur, the conductor loading should be based on actual local conditions.

The ice loading can be determined from the following equations:

$$W_I = 0.704\ (d_1^2 - d_2^2) \quad (W_I = 0.311\ (d_1^2 - d_2^2)) \qquad \text{IV-9}$$

W_I: ice loading, in newtons per meter (pounds per foot)

d_1: outside diameter of conductor with ice, in centimeters (inches) (Determine ice thickness from Table IV-12.)

d_2: outside diameter of conductor without ice, in centimeters (inches)

The wind loading can be determined from the following equations:

$$F_W = 0.01\ P_W d_1 \qquad (F_W = 0.083\ P_W d_1) \qquad \text{IV-10}$$

F_W: wind loading, in newtons per meter (pounds per foot)

P_W: wind pressure, in pascals (pounds per foot^2) (from Table IV-12)

d_1: outside diameter of conductor with ice, in centimeters (inches) (Determine ice thickness from Table IV-12.)

The total bus conductor loading can be determined from the following equation:

$$F_T = [F_W^2 + (W_C + W_I)^2]^{\frac{1}{2}} + k \qquad \text{IV-11}$$

F_T: total bus conductor loading, in newtons per meter (pounds per foot)

F_W: wind loading, in newtons per meter (pounds per foot)

W_C: conductor weight, in newtons per meter (pounds per foot)

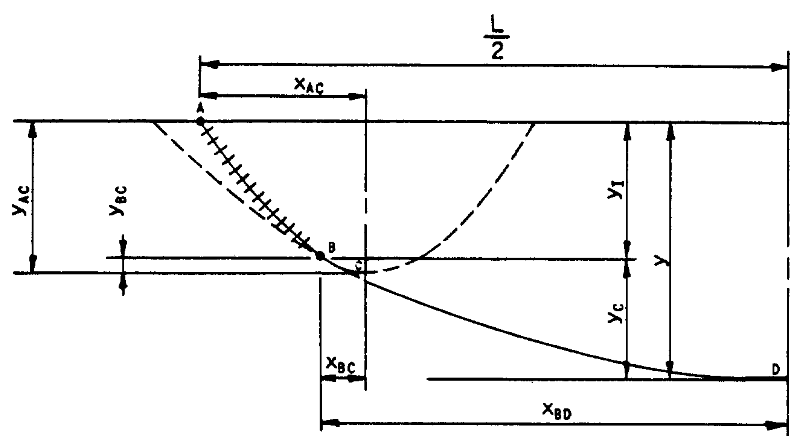
W_I: ice loading, in newtons per meter (pounds per foot)

k: NESC constant (from Table IV-12)

e. Calculate or obtain the maximum conductor sag. Methods for this calculation can be found in conductor manufacturers' literature. In some cases the maximum sag may occur during the most severe loading condition. For substation strain buses, the design tension is usually limited to 13,350 newtons (3000 pounds) per conductor under the most severe loading to minimize the size of support structures. These conductor tensions must be coordinated with the support structure designs to ensure compatibility under all loading conditions. The tensions that will occur under unloaded conditions will be considerably less than the maximum.

For light loading conditions where ice loads are not considered, the maximum conductor sag may occur at the highest conductor temperature when the conductor length is at a maximum. For other loading conditions, sags should be determined for both high conductor temperatures and maximum loading so that adequate clearance from other equipment can be provided.

f. Calculate the suspension insulator effect on conductor sag. For short dead-ended spans, such as substation strain buses, the suspension insulators can have an appreciable effect on span sags. The following procedure can be used to calculate the insulator effect, which is added to the conductor sag for the total bus sag.



$$C_I = \frac{T_C}{W_{IN}} \qquad \text{IV-12}$$

$$C_C = \frac{T_C}{W_C} \qquad \text{IV-13}$$

$$x_{BC} = \frac{C_I}{C_C} x_{BD} \text{ (Assume } x_{BD} = \frac{L}{2} - l_{AB}) \qquad \text{IV-14}$$

$$y_{BC} = C_I \left[\left(\cosh \frac{x_{BC}}{C_I}\right) - 1\right] \qquad \text{IV-15}$$

$$l_{AC} = l_{AB} + C_I \sinh \frac{x_{BC}}{C_I} \qquad \text{IV-16}$$

$$x_{AC} = C_I \sinh^{-1} \frac{l_{AC}}{C_I} \qquad \text{IV-17}$$

$$y_{AC} = C_I \left[\left(\cosh \frac{x_{AC}}{C_I}\right) - 1\right] \qquad \text{IV-18}$$

$$y_I = y_{AC} - y_{BC} \qquad \text{IV-19}$$

$$y = y_I + y_C \qquad \text{IV-20}$$

C_I: insulator catenary constant, in meters (feet)

C_C: conductor catenary constant, in meters (feet)

x_{AC}: horizontal distance from insulator support point to center of insulator catenary, in meters (feet)

x_{BC}: horizontal distance from connection point of insulator string and conductor to center of insulator catenary, in meters (feet)

x_{BD}: horizontal distance from connection point of insulator string and conductor to center of conductor catenary, in meters (feet)

l_{AB}: length of insulator string, in meters (feet)

l_{AC}: arc length from insulator support point to center of insulator catenary, in meters (feet)

y_{AC}: sag from insulator support point to center of insulator catenary, in meters (feet)

y_{BC}: sag from connection point of insulator string and conductor to center of insulator catenary, in meters (feet)

y_I: insulator sag, in meters (feet)

y_C: conductor sag, in meters (feet)

y: total bus sag, including insulators and conductor, in meters (feet)

T_C: horizontal conductor tension, in newtons (pounds)

W_{IN}: insulator string weight, in newtons per meter (pounds per foot)

W_C: conductor weight, in newtons per meter (pounds per foot)

L: span length, in meters (feet)

g. Calculate and chart stringing tensions and corresponding sags for a range of expected conductor temperatures during installation. Base the calculations on the assumed maximum tension that occurs under the most severe conductor loading. To be included in the chart and listed on the installation drawings are span length, tension, and total bus sag for various conductor temperatures. Methods to determine the sags and tensions can be found in conductor manufacturers' literature.

After the conductor sags are calculated, add the suspension insulator sag to the conductor sags to determine the total bus sags as described in Section L2(f) of this chapter.

h. <u>Example Calculation of Bus Conductor Loading</u>

Calculate the total bus conductor loading for the following strain bus:

Span length:	60.96 meters (200 feet)
Voltage:	161 kV
BIL:	750 kV
Conductor size:	795 kcmil 26/7 ACSR
Conductor diameter:	2.81 cm (1.108 in)
Conductor weight:	16.0 N/m (1.094 lb/ft)
NESC loading:	heavy

Ice loading: Select ice thickness from Table IV-12.

$W_I = 0.704\ (d_1^2 - d_2^2)$ $\quad$ $(W_I = 0.311\ (d_1^2 - d_2^2))$

$W_I = (0.704)\ [(5.35)^2 - (2.81)^2]$ $\quad$ $(W_I = (0.311)\ [(2.108)^2 - (1.108)^2])$

$W_I = 14.6$ N/m $\quad$ $(W_I = 1.0$ lb/ft$)$

Wind loading: Select wind pressure from Table IV-12.

$F_W = 0.01\ P_W d_1$ $\quad$ $(F_W = 0.083\ P_W d_1)$

$F_W = (0.01)(191.5)(5.35)$ $\quad$ $(F_W = (0.083)(4)(2.108))$

$F_W = 10.2$ N/m $\quad$ $(F_W = 0.70$ lb/ft$)$

Total bus conductor loading:

$$F_T = [F_W^2 + (W_C + W_I)^2]^{1/2} + k \qquad (F_T = [F_W^2 + (W_C + W_I)^2]^{1/2} + k)$$

$$F_T = [(10.2)^2 + (16.0 + 14.6)^2]^{1/2} + 4.38 \qquad (F_T = [(0.70)^2 + (1.094 + 1.0)^2]^{1/2} + 0.30)$$

$$F_T = 36.6 \text{ N/m} \qquad (F_T = 2.51 \text{ lb/ft})$$

i. Example Calculation of Suspension Insulator Effect on Bus Sag

Calculate the suspension insulator effect on bus sag for the following strain bus:

Span length:	60.96 meters (200 feet)
Voltage:	161 kV
BIL:	750 kV
Conductor size:	795 kcmil 26/7 ACSR
Conductor diameter:	2.81 cm (1.108 in)
Conductor weight:	16.0 N/m (1.094 lb/ft)
Conductor tension:	8896 N (2000 lb)
Number of suspension insulators (from Table IV-5):	10
Length of each insulator:	14.6 cm (5.75 in)
Weight of each insulator:	48.9 N (11.0 lb)

$$C_I = \frac{T_C}{W_{IN}} \qquad \left(C_I = \frac{T_C}{W_{IN}}\right)$$

$$C_I = \frac{8896}{\frac{48.9}{(14.6)\ (\frac{1}{100})}} \qquad \left(C_I = \frac{2000}{\frac{11}{(5.75)\ (\frac{1}{12})}}\right)$$

$$C_I = 26.6 \text{ m} \qquad (C_I\ 87.1 \text{ ft})$$

$$C_C = \frac{T_C}{W_C} \qquad \left(C_C = \frac{T_C}{W_C}\right)$$

$$C_C = \frac{8896}{16} \qquad \left(C_C = \frac{2000}{1.094}\right)$$

$$C_C = 556 \text{ m} \qquad (C_C = 1828 \text{ ft})$$

$$x_{BC} = \frac{C_I}{C_C}\, x_{BD} \qquad \left(x_{BC} = \frac{C_I}{C_C}\, x_{BD}\right)$$

$$x_{BC} = \frac{26.6}{556}\left(\frac{60.96}{2} - \frac{(10)(14.6)}{100}\right) \qquad \left(x_{BC} = \frac{87.1}{1828}\left(\frac{200}{2} - \frac{(10)(5.75)}{12}\right)\right)$$

$$x_{BC} = 1.39 \text{ m} \qquad (x_{BC} = 4.54 \text{ ft})$$

$$y_{BC} = C_I\left[\left(\cosh \frac{x_{BC}}{C_I}\right) - 1\right] \qquad \left(y_{BC} = C_I\left[\left(\cosh \frac{x_{BC}}{C_I}\right) - 1\right]\right)$$

$$y_{BC} = (26.6)\left[\left(\cosh \frac{1.39}{26.6}\right) - 1\right] \qquad \left(y_{BC} = (87.1)\left[\left(\cosh \frac{4.54}{87.1}\right) - 1\right]\right.$$

$y_{BC} = 0.0363$ m $\qquad$ ($y_{BC} = 0.118$ ft)

$$l_{AC} = l_{AB} + C_I \sinh \frac{x_{BC}}{C_I}$$ $\qquad$ $$(l_{AC} = l_{AB} + C_I \sinh \frac{x_{BC}}{C_I})$$

$$l_{AC} = (10) \frac{(14.6)}{(100)} + (26.6) \sinh \frac{1.39}{26.6}$$ $\qquad$ $$l_{AC} = (10) \frac{(5.75)}{(12)} + (87.1) \sinh \frac{4.54}{87.1})$$

$l_{AC} = 2.85$ m $\qquad$ ($l_{AC} = 9.33$ ft)

$$x_{AC} = C_I \sinh^{-1} \frac{l_{AC}}{C_I}$$ $\qquad$ $$(x_{AC} = C_I \sinh^{-1} \frac{l_{AC}}{C_I})$$

$$x_{AC} = (26.6) \sinh^{-1} \frac{2.85}{26.6}$$ $\qquad$ $$(x_{AC} = (87.1) \sinh^{-1} \frac{9.33}{87.1})$$

$x_{AC} = 2.84$ m $\qquad$ ($x_{AC} = 9.31$ ft)

$$y_{AC} = C_I [(\cosh \frac{x_{AC}}{C_I}) - 1]$$ $\qquad$ $$(y_{AC} = C_I [(\cosh \frac{x_{AC}}{C_I}) - 1])$$

$$y_{AC} = (26.6) [(\cosh \frac{2.84}{26.6}) - 1]$$ $\qquad$ $$(y_{AC} = (87.1) [(\cosh \frac{9.31}{87.1}) - 1]$$

$y_{AC} = 0.152$ m $\qquad$ ($y_{AC} = 0.498$ ft)

$y_I = y_{AC} - y_{BC}$ $\qquad$ ($y_I = y_{AC} - y_{BC}$)

$y_I = 0.152 - 0.0363$ $\qquad$ ($y_I = 0.498 - 0.118$)

$Y_I = 0.116$ m $\qquad$ ($Y_I = 0.38$ ft)

The value calculated for y_I is then added to the conductor sag to determine the total bus sag. Use $2x_{BD}$ as the span length to calculate the conductor sag.

M. APPLICATION OF MOBILE TRANSFORMERS AND SUBSTATIONS

Mobile transformers or mobile substations can be used to provide temporary service during equipment maintenance, construction, emergency, or high load periods. Sufficient mobile units strategically placed can reduce or eliminate the requirements for on-site spare transformers.

Several aspects should be considered in applying mobile transformers or substations. To be considered are:

1. Size and maneuverability of the equipment
2. Installation location and provisions
3. Electrical clearances
4. Primary and secondary connections
5. Grounding
6. Auxiliary system requirements
7. Safety

1. Size and Maneuverability of the Equipment

One of the primary advantages of mobile equipment is its ability to be used at more than one location. To accommodate installation, adequate space must be available to position and connect the equipment at all intended locations. It may be impossible to use larger units in some locations without substantial modifications because of the lack of sufficient space.

Substation entrances and access roads should be evaluated before committing particular equipment to the location in question. Prior planning can save much time and facilitate installation.

2. Installation Location and Provisions

The mobile transformer or substation location should permit primary and secondary connections as short as possible to the permanent substation equipment. It is desirable to utilize bare conductors for the connections. Sometimes, insulated cables can be used where electrical clearances cannot be maintained or where connections are long. The location should permit any required connections to be made quickly and safely without disturbing adjacent equipment. The ease and speed of installation can be influenced by the proximity of energized equipment.

Substations for which mobile equipment has been designated should have provisions for installation of the equipment. The provisions can simply be terminals on permanent substation equipment or buses for connecting the mobile equipment. It may be desirable to include bus extensions and/or disconnect switches in some substations to facilitate the connections, particularly if they may be made while the substation is energized.

If low voltage ac or dc supplies are required, permanent facilities can be provided in the vicinity where the mobile equipment will be positioned. A weatherproof cabinet containing any necessary terminal blocks, switches, or protective devices can be provided for terminating the low voltage circuits. Temporary connections can be made from this cabinet to the control cabinet on the mobile equipment. Connections into the substation alarm system can also be provided in this or another cabinet. Terminal blocks, test switches, indicating lamps, or any other necessary equipment can be located in the cabinet.

Provisions for grounding the equipment can consist of terminals or ground rods connected to the main grounding grid.

3. Electrical Clearances

Maintaining adequate electrical clearances between the mobile equipment, its connections, and other equipment is of prime importance. Installation using bare conductors should not be considered for a location, unless the minimum clearances listed in Tables IV-6 and IV-7 in Section I of this chapter can be maintained. Insulated conductors can be used in some locations if the minimum clearances cannot be maintained.

4. Primary and Secondary Connections

All primary and secondary connections should be as short as possible and should be made with bolted connections. If possible, bare conductors should be used. However, for situations where minimum electrical clearances cannot be maintained or where connections are long, insulated conductors can be employed.

Conductors used should be sized to carry the maximum loads expected without overheating and to sustain anticipated fault currents without damage. They should be checked for sufficient length before connecting either end.

Temporary poles or structures may be required in some locations to facilitate the connections and maintain clearances. It is desirable to store any necessary equipment not part of the mobile unit at the substations, where required.

5. Grounding

Adequate grounding of mobile transformers and substations is extremely important for safe operation. At least two independent connections should be made between the trailer and the ground system. The mobile equipment should be connected to the substation ground grid whenever in close proximity to the substation. In situations where the mobile is located a long distance away from the substation and connection to the substation ground grid is impractical, a separate ground system must be provided.

6. Auxiliary System Requirements

Mobile unit transformers are usually designed for forced-cooled operation. Some units can provide the low voltage necessary for auxiliary equipment operation through the use of an on-board supply transformers and equipment. For units without these provisions, low voltage supplies can be obtained from the substation station service system.

Before the substation station service system is used to supply mobile unit auxilary systems, the voltage(s) required by the auxiliary systems must be checked against those available at the substation for compatibility. The system should also be checked for adequate capacity.

If an external dc supply is necesary for power or control applications, the substation control battery can be used. The system should be checked for proper voltage and adequate capacity prior to utilization.

7. Safety

Unless the mobile equipment is completely contained within another fenced area, a separate fence should be provided to surround the equipment. The fence must provide the same security and protection as would a permanent substation fence. Gates should be provided with adequate locking facilities.

Mobile equipment usually requires some assembly during installation. Barriers and supports may require installation. Some supporting members or braces used to protect the equipment during transit may have to be removed. Assembly and installation should be in strict accordance with the manufacturer's instructions.

The equipment should be positioned on a level site and blocked to prevent movement. Ground slope at the installation location should not exceed the manufacturer's recommendations.

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LEGEND

C_C: Conductor catenary constant

C_I: Insulator catenary constant

D : Centerline-to-centerline spacing of bus conductors

d_1: Outside diameter of bus conductor with ice

d_2: Outside diameter of bus conductor without ice

E : Modulus of elasticity

W_C: Bus conductor weight per unit length

W_I: Ice loading on bus conductor per unit length

W_{IN}: Insulator string weight per unit length

F_{SC}: Short-circuit force on bus conductor per unit length

F_T: Total bus conductor loading per unit length

F_W: Wind loading on bus conductor per unit length

F_B: Maximum desirable bus conductor fiber stress

I : Moment of inertia

i : Short-circuit current

k : NESC conductor loading constant

K_{SC}: Short-circuit force reduction factor

K_{DE}: Multiplying factor for maximum vertical conductor deflection

K_{DM}: Multiplying factor for maximum vertical conductor deflection

K_{SE}: Multiplying factor for maximum bus support spacing

K_{SM}: Multiplying factor for maximum bus support spacing

L : Bus span length

L_M: Maximum bus support spacing

L_S: Conductor length for calculating insulator cantilever strength

Δl: Conductor expansion (final length minus initial length)

l : Initial conductor length

l_{AB}: Length of insulator string

l_{AC}: Arc length from insulator support point to center of insulator catenary

P_W: Wind pressure on projected area of bus conductor

S : Bus conductor section modulus

ΔT: Bus conductor temperature variation (final temperature minus initial temperature)

T_C: Horizontal bus conductor tension

W_S: Minimum insulator cantilever strength

x_{AC}: Horizontal distance from insulator support point to center of insulator catenary

x_{BC}: Horizontal distance from connection point of insulator string and conductor to center of insulator catenary

x_{BD}: Horizontal distance from connection point of insulator string and conductor to center of conductor catenary

y: Total bus sag or deflection

y_{AC}: Sag from insulator support point to center of insulator catenary

y_{BC}: Sag from connection point of insulator string and conductor to center of insulator catenary

y_I: Insulator sag

y_C: Conductor sag

y_{max}: Maximum permissable conductor deflection

α: Coefficient of linear thermal expansion

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INDEX

International System of Units

In December 1975, Congress passed the "Metric Conversion Act of 1975." This Act declares it to be the policy of the United States to plan and coordinate the use of the Metric system.

The metric system, designated as the International System of Units (SI), is presently used by most countries of the world. The system is a modern version of the meter, kilogram, second, ampere (MKSA) system which has been in use for years in various parts of the world.

To promote greater familiarization of the metric system in anticipation of the U.S. converting to the system, REA is including metric units in its publications. This bulletin has, therefore, been prepared with the International System of Units (SI) obtained from ANSI Z 210-1976 - Metric Practice. Approximately equivalent Customary Units are also included to permit ease in reading and usage, and to provide a comparison between the two systems.

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